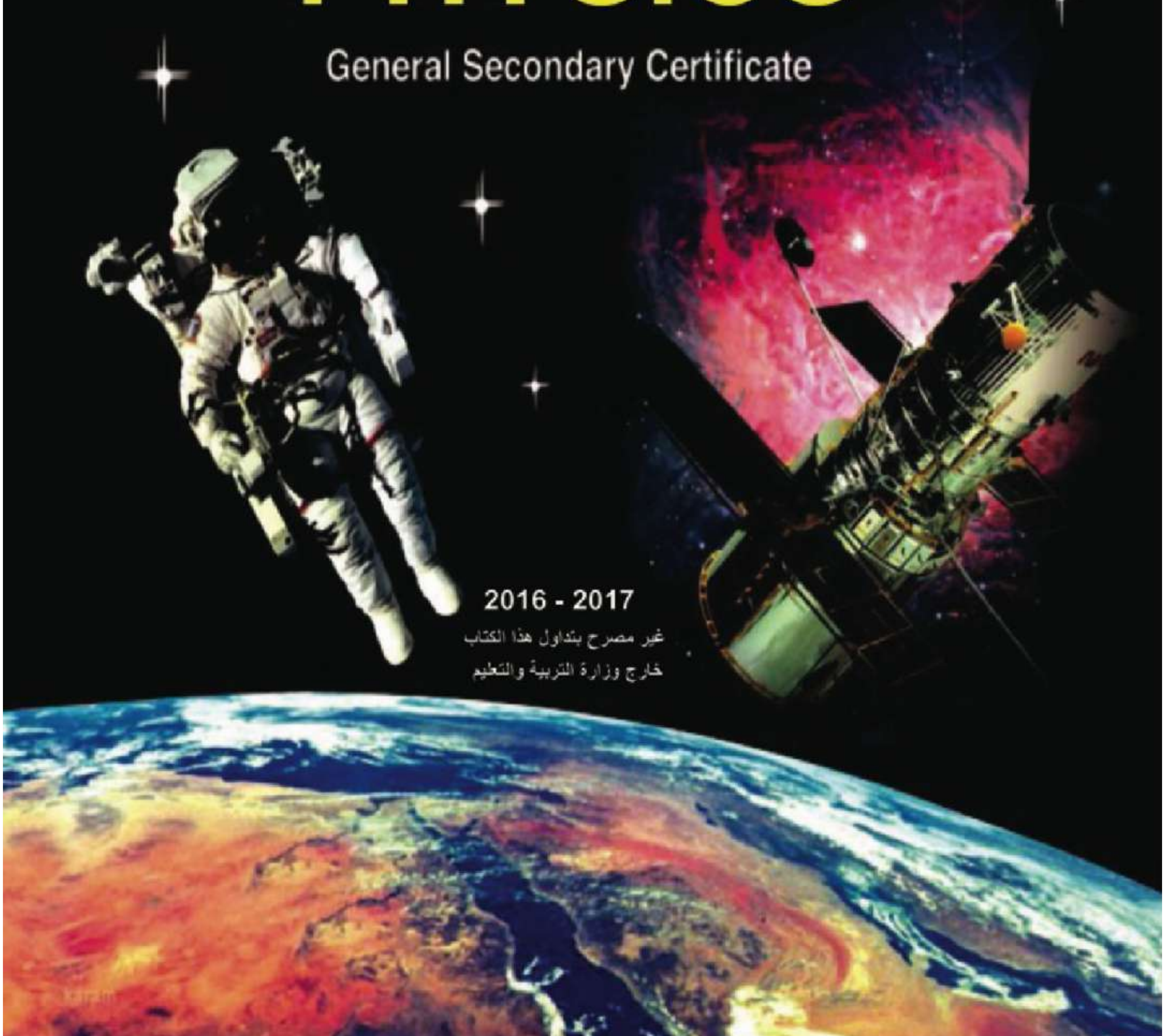
Arab Republic of Egypt
Ministry of Education
Book Sector

PHYSICS

General Secondary Certificate



2016 - 2017

غير مصرح بتداول هذا الكتاب
خارج وزارة التربية والتعليم

Arab republic of egypt
Ministry of Education
Book Sector

Physics

General Secondary Certificate

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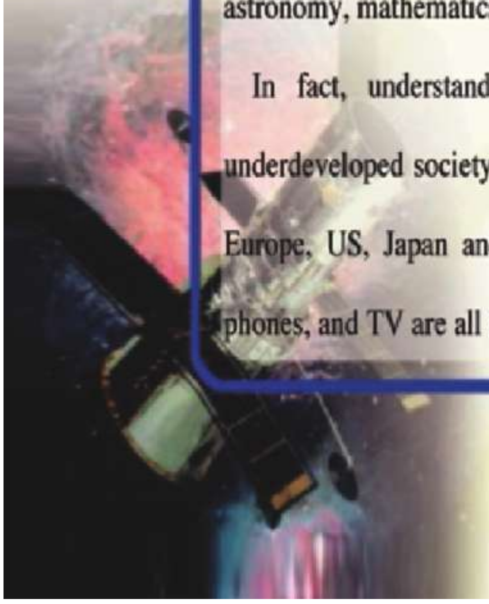
Foreword

Physics is the cornerstone of basic sciences. It deals with the understanding of nature and what goes around us, big and small in this universe. It is the root of all sciences. Interwined with it is chemistry which focuses on reactions between materials, biology which deals with living creatures, geology which is involved with the layers of the Earth, and astronomy which treats celestial objects. But in the end, physics remains the mother of all sciences and the basis for the tremendous present scientific and technological progress. Understanding physics means understanding the laws governing this universe. Such understanding has led to the current industrial development spearheaded by the West. The Arabs and Moslems were once the pioneers of civilization in the world when they realized the importance of understanding the laws of this universe. We owe them the discovery of most laws of physics centuries before the West. The foundations of medicine, physics, chemistry, astronomy, mathematics and music were all laid by Arab and Moslem scientists.

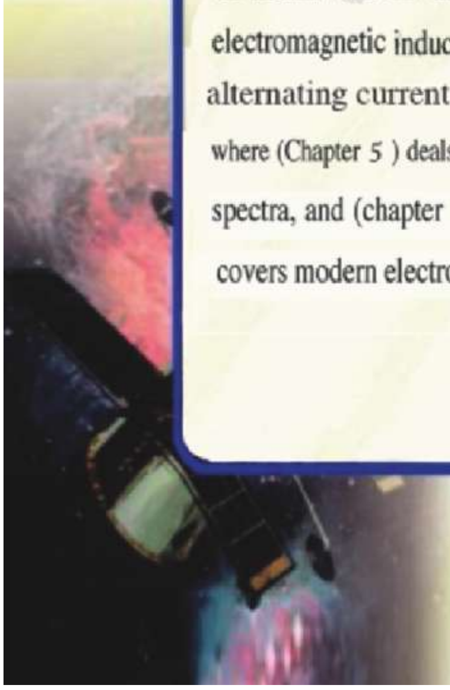
In fact, understanding physics and its applications converts a poor, and underdeveloped society into an affluent and developed one. This has taken place in Europe, US, Japan and South East Asia. Computers, satellites, cellular (mobile) phones, and TV are all byproducts of physics. Genetics is currently being looked into



intensively. It is targeted to use genetics, atoms and lasers in the computer of the future. It is a limitless world, enriched by imagination, where sky is the limit.

The scientific progress is a cumulative effort. This collective endeavor has led to where we are today. A scholar of physics must be acquainted with such accumulated knowledge in a short time, so that he could add to it within the limited span of his life. In studying what others have found, we must skip details and trials, and extract the end results and build on them.A global view is, therefore, more important at this stage than being drowned in minute details that could be postponed to a later stage of study.

This book is divided into 3 units. Unit 1 treats electricity, where (chapter 1) covers the electric current, Ohm's law, (chapter 2) covers the magnetic effects of electric current and measuring instruments, while (chapter 3) covers electromagnetic induction. Finally, chapter 4 deals with the circuits of alternating current Unit 2 gives an introduction to modern physics, where (Chapter 5) deals with wave particle duality, (Chapter 6) deals with atomic spectra, and (chapter 7) deals with lasers and their applications, while (chapter 8) covers modern electronics.



Suzanne Mubarak Science Exploration Center has carried out the preparation, and the typing of manuscript as well as the design of the artwork.

In the end, we want the student to take liking to physics. For this is the way to the future. We want the teacher to teach the subject of physics in an innovative way, to arouse the interest of the students by constantly referring to the use and applications of physics in the daily life. We hope that one day we will have great inventors and industrialists among today's students.

Committee for the preparation of this new version of the textbook.

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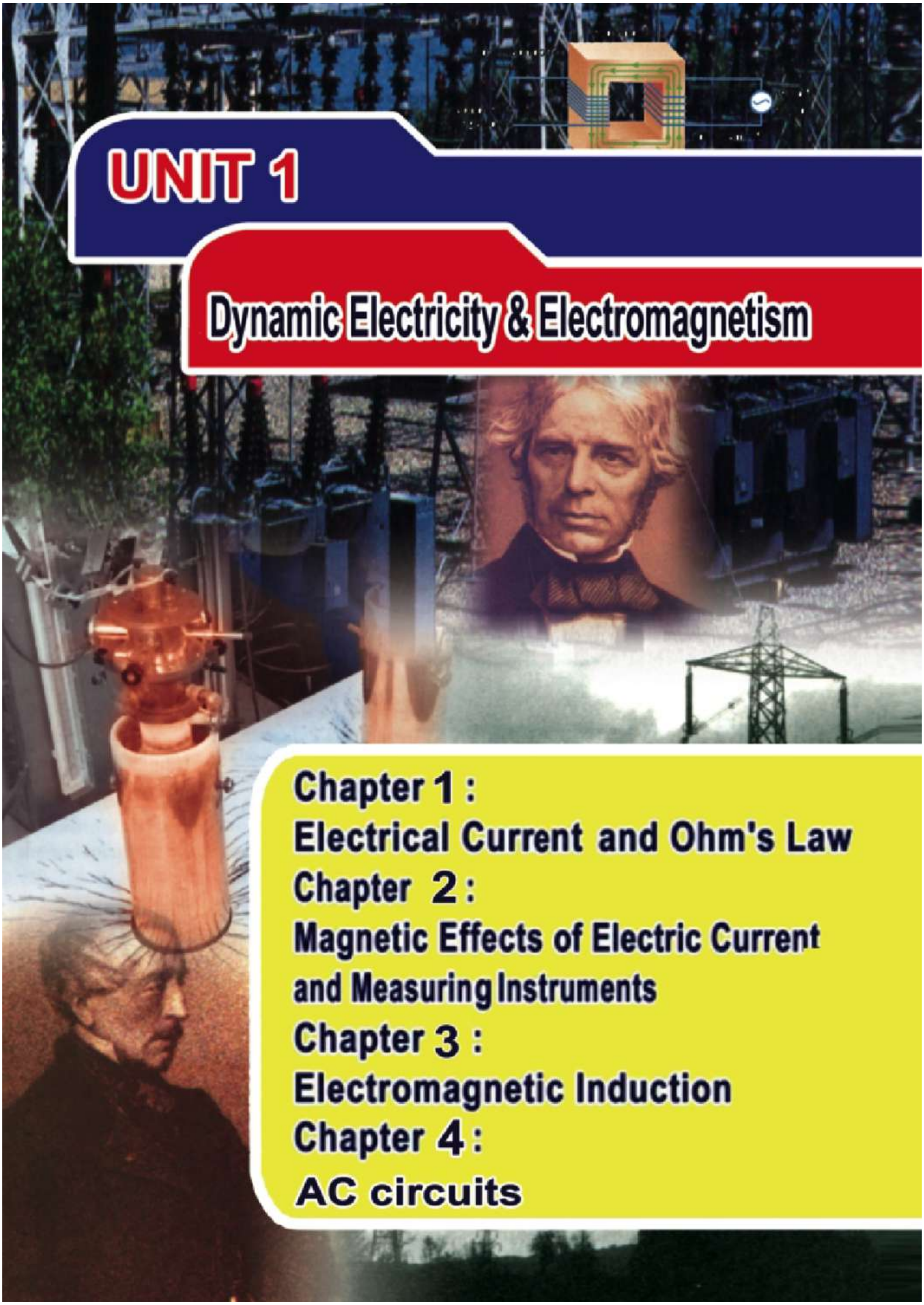


UNIT 1

Dynamic Electricity & Electromagnetism

Chapter 1 :
Electrical Current and Ohm's Law

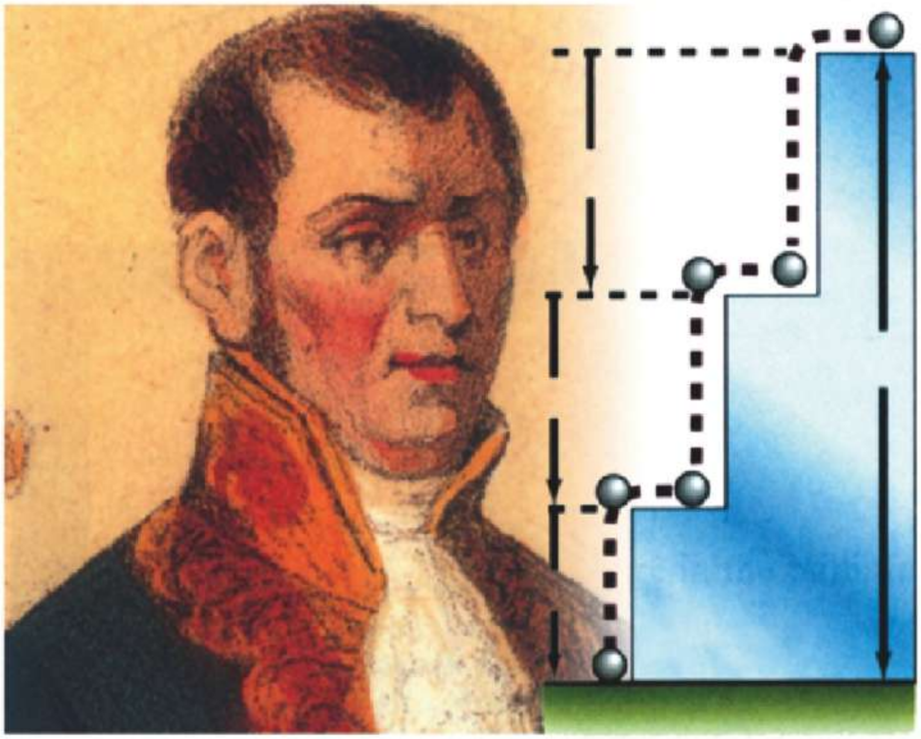
Chapter 2 :
Magnetic Effects of Electric Current and Measuring Instruments

Chapter 3 :
Electromagnetic Induction

Chapter 4 :
AC circuits

Dynamic Electricity & Electromagnetism

UNIT 1



Chapter 1:
Electrical Current and Ohm's Law

Chapter 1 Electric Current and Ohm's Law

Overview

We have learned from the previous study that :

1) the electric current is a flow of electric charges in a conducting material.

Ohm

2) the intensity of an electric current I is given by the relation $I = \frac{Q}{t}$, where Q is the quantity of electricity (Coulomb-C), t is time (s) and I is measured in Amper(A).

1A = Coulomb/sec (C/s).

3) the potential difference between two points: $V = \frac{W}{Q}$, where W is the work done (Joule), V is the potential difference in 1 Volt(V) = Joule/C.

Ampere

4) the emf of a source is the total work done to transfer unit charge (Coulomb) throughout the circuit outside and inside the source. It has units of volt .

5)the resistance R is measured in Ohm (Ω) and depends on the length of the conductor, its cross sectional area and its material at constant temperature. It is given by the relation $R = \frac{\rho_e \ell}{A}$, where ℓ is the length of the conductor (m),A is the cross

sectional area (m^2) and (ρ_e) is the resistivity (Ωm).The electrical conductivity of a certain material σ ($\Omega^{-1}m^{-1}$) is the reciprocal of the resistivity $\sigma = (\frac{1}{\rho_e})$.

6) Ohm's Law:

The current intensity in a conductor is directly proportional to the potential difference across its terminals at a constant temperature : $\boxed{V = IR}$

7) as a convention, the direction of flow of the electric current always goes from the positive terminal to the negative terminal outside the source into a closed electric circuit. It is opposite to the direction of motion of electrons. It is called the conventional direction of current.

Connecting resistors

Firstly: series connection

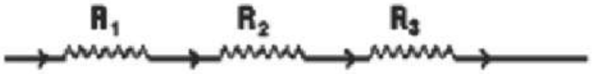


Fig (1 – 1)

Connection in series

Resistors are connected in series to obtain a higher resistance (Fig1–1). The equivalent resistance of a group of resistors connected in series can be obtained in connecting these resistors in an electric circuit comprising a battery,an ammeter,a rheostat (variable resistor) and a switch (Fig 1-2). The circuit is closed and the rheostat is adjusted so that an appropriate current I is passed. The voltage difference across each resistor is measured (V_1 across R_1, V_2 across R_2, V_3 across R_3) as well as the total voltage (V), which is equal to the sum of the voltage differences across the resistors in the series circuit.

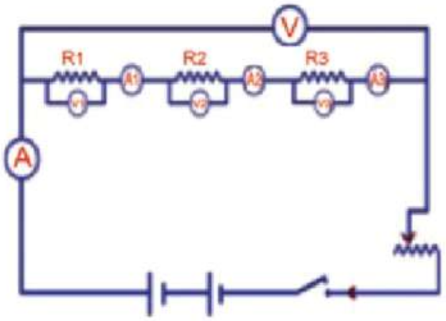


Fig (1 – 2)
Measuring the equivalent resistance in a series connection

$$V' = V_1 + V_2 + V_3$$

But $\because V = IR$

$$V_1 = IR_1$$

$$V_2 = IR_2$$

$$V_3 = IR_3$$

$$\boxed{IR' = IR_1 + IR_2 + IR_3}$$

$$R' = R_1 + R_2 + R_3$$

Thus, the equivalent resistance R of a group of resistors connected in series equals the sum of these resistances. It is to be noted that the largest resistance in the combination determines the total resistance in a series connection. If N resistances are connected in series each equal r then :

$$\boxed{R' = Nr}$$

We conclude that if we want a large resistance out of a bunch of small resistances, we simply connect them in series.

Secondly: Parallel connection

The purpose of connecting resistors in parallel is to obtain a small resistance out of a bunch of large resistances (Fig 1 – 3). To obtain the equivalent resistance for a parallel connection, the combination is included in an electric circuit comprising a battery, an ammeter and a rheostat all connected as shown (Fig 1 – 4).

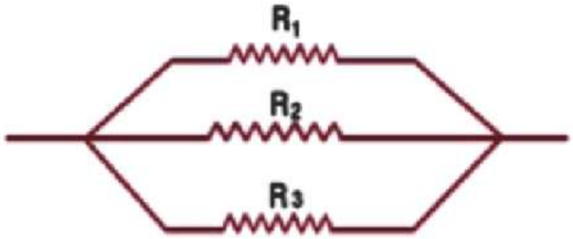


Fig (1 – 3)
Connection in parallel

We close the circuit and adjust the rheostat to obtain an appropriate current in the main circuit of intensity I (A), which can be measured by the ammeter. The total voltage difference can then be measured across the terminals of the resistances by a voltmeter (V). The current in each branch is measured (I_1 in R_1, I_2 in R_2, and I_3 in R_3). In a parallel connection, the total current is determined by the smallest resistance. This case is similar to the flow of water in pipes.

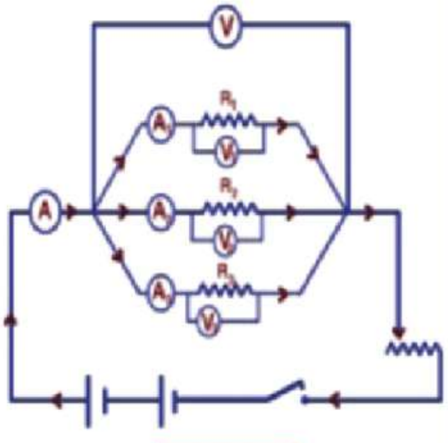


Fig (1 - 4)
Measuring the equivalent resistance in a parallel connection

The smallest pipe (the highest resistance) determines the flow rate in a series connection, while the widest pipe (the least resistance) determines the rate of flow in a parallel connection, since it draws most of the water current.

It is to be noted that :

$$I = \frac{V}{R'} \ , \ I_1 = \frac{V}{R_1} \ , \ I_2 = \frac{V}{R_2} \ , \ I_3 = \frac{V}{R_3}$$

where $\acute{R}$ is the equivalent resistance, and V is the voltage difference across resistors connected in parallel. The total current I is the sum of the branch currents. $I_1 + I_2 + I_3$.

Thus:

$$\frac{V}{R'} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\boxed{\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Hence, the reciprocal of the equivalent resistance $\acute{R}$ is the sum of the reciprocal of resistances in the case of a parallel connection. In the case of two resistors in parallel, the equivalent resistance $\acute{R}$ is given by :

$$\boxed{\acute{R} = \frac{R_1 R_2}{R_1 + R_2}} \qquad (1-4)$$

When N resistances are connected in parallel each equal to r,

$$\frac{1}{R'} = \frac{N}{r}$$

$$\boxed{\acute{R} = \frac{r}{N}} \qquad (1-5)$$

Therefore, if we wish to obtain a small resistance out of a bunch of resistors, we simply connect them in parallel.

Ohm's Law for a closed circuit

We know that the emf of an electric cell (battery - source) is the total work done inside and outside the cell to transfer an electric charge of 1C in the electric circuit. If we denote the emf of a battery by V_B, the total current in the circuit by I, the external resistance by R and the internal resistance of the cell by r, then

$$V_B = IR + Ir$$

$$V_B = I(R + r)$$

$$\boxed{I = \frac{V_B}{R + r}}$$

This is known as Ohm's law for a closed circuit, from which we find that the current intensity in a closed circuit is the emf of the total source divided by the total (external plus internal) resistance of the circuit.

Relation between emf and voltage across a source

From Fig (1 – 5), we find

$$\boxed{V = V_B - Ir}$$

From this relation, we see that as I is decreased gradually in the circuit shown (Fig 1– 5), by increasing the external resistance R, the voltage difference across the source increases.

When the current vanishes, the voltage difference across the source becomes equal to the emf of the source. Hence, we may define the emf of a source as the voltage difference across it when the current ceases to flow in the circuit.

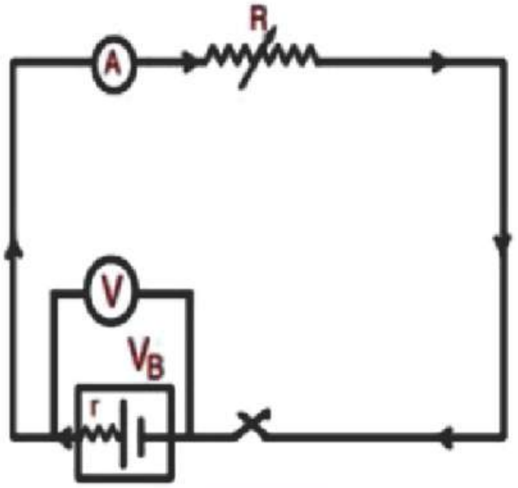


Fig (1-5)

Relation between the voltage difference and the emf of a source

Examples:

1) Three resistors 25Ω, 70Ω and 85Ω are connected in series to a 45 volt battery of a negligible internal resistance. Calculate:

a) the current flowing in each resistor.

b) the potential difference across each resistor .

Solution :

The total resistance of the circuit R is :

$$R = R_1 + R_2 + R_3 = 25 + 70 + 85 = 180\ \Omega$$

The current flowing through the circuit is:

$$I = \frac{V_B}{R} = \frac{45}{180} = 0.25\ A$$

Since the resistors are connected in series, then the current flowing through each and all other parts of the circuit is the same, i.e., 0.25 A. Assume that the potential difference across R_1, R_2, R_3 are V_1, V_2, V_3, respectively.

$$V_2 = IR_2 = 0.25 \times 70 = 17.5V$$

$$V_1 = IR_1 = 0.25 \times 25 = 6.25V$$

$$V_3 = IR_3 = 0.25 \times 85 = 21.25V$$

2) If the resistors in the previous example are connected in parallel to the same battery, calculate:

a) the current flowing in each resistor.

b) the total resistance.

c) the current through the circuit.

solution :

a) the voltage difference across each resistor = 45V, since they are connected in parallel and the battery is of negligible internal resistance. The current flowing through each resistor is calculated separately as follows :

$$I_1 = \frac{V}{R_1} = \frac{45}{25} = 1.8 \text{ A}$$

$$I_2 = \frac{V}{R_2} = \frac{45}{70} = 0.643 \text{ A}$$

$$I_3 = \frac{V}{R_3} = \frac{45}{85} = 0.529 \text{ A}$$

b)The total (equivalent or combined) resistance R is calculated as follows :

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{25} + \frac{1}{70} + \frac{1}{85}$$

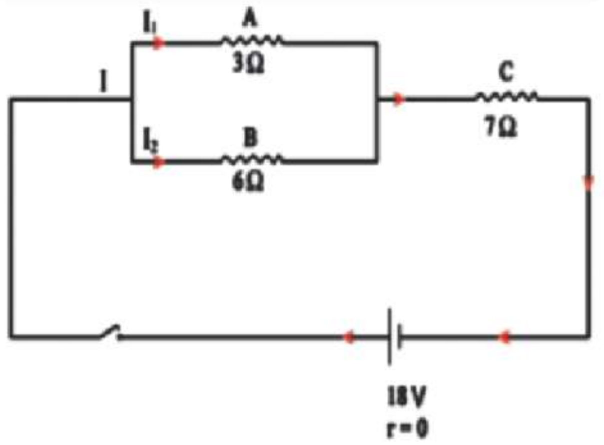
$$R' = 15.14\,\Omega$$

c) The current flowing through the circuit I is :

$$I = \frac{V}{R'} = \frac{45}{15.14} = 2.972 \text{ A}$$

It can be calculated also as the sum of the currents I_1 , I_2 , I_3 flowing through all resistors:

$$I = 1.8 + 0.643 + 0.529 = 2.972 \text{ A}$$



3) In the figure shown above two resistors A and B are connected in parallel. The combination is connected in series with a resistor C and a 18 volt battery of negligible internal resistance. If the resistances of A,B and C are 3Ω,6Ω,7Ω, respectively, calculate:

a) the total resistance.

b) the current flowing through the circuit.

c) the current through each of A and B.

Solution :

The equivalent resistance for the combination (A, B) is :

$$R' = \frac{R_1 R_2}{R_1 + R_2} = \frac{3 \times 6}{3 + 6} = 2\ \Omega$$

The equivalent resistance for the combination (A,B)and(C) is :

$$R = R' + R_3 = 2 + 7 = 9\ \Omega$$

The current I flowing through the circuit is :

$$I = \frac{V}{R} = \frac{18}{9} = 2\ A$$

To calculate the current flowing through each of A and B, we should calculate the potential difference $\acute{V}$ across the combination (A, B) :

$$\acute{V} = I\acute{R} = 2 \times 2 = 4V$$

Assuming the current flowing through A and B to be I_1 and I_2, respectively:

$$\therefore I_1 = \frac{\acute{V}}{R_1} = \frac{4}{3} = 1.333$$

$$\therefore I_2 = \frac{\acute{V}}{R_2} = \frac{4}{6} = 0.667$$

4) A cell of e.m.f. 2V and internal resistance 0.1Ω is connected to a circuit of external resistance 3.9Ω. Calculate the current flowing through the circuit.

Solution :

$$I = \frac{V_B}{R + r} = \frac{2}{3.9 + 0.1} = 0.5\ A$$

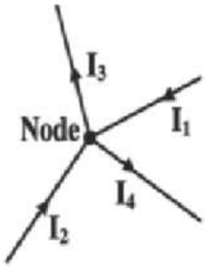
Kirchhoff's laws

Some electric circuits are too complicated to be managed by applying Ohm's law. For such cases there are a set of relations called **Kirchhoff's laws** which enable one to analyze arbitrary circuits.

Kirchhoff's First Law: "based on conservation of electric charge"

You know that the electric current through metallic conductors is a stream of negative free electrons (electric charges) flowing from one point to another and these charges do not accumulate at any point along their path through the conductor. According to this Kirchhoff has formulated his first law (**Kirchhoff's current law**) as follows:

"At any node (junction) in an electrical circuit, the sum of currents flowing into the node is equal to the sum of currents flowing out of that node"



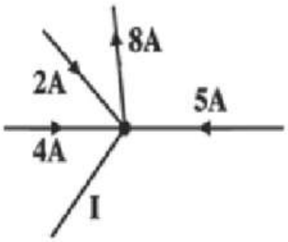
As shown in figure:

$I_1 + I_2 = I_3 + I_4$

$I_1 + I_2 - I_3 - I_4 = 0$

"The algebraic sum of electric currents meeting at a point (a node) in a closed circuit equals zero". This can be expressed as: $\sum I = 0$

Example: Calculate the intensity and the direction of the electric current (I) illustrated in the given figure.



Solution:

According to Kirchhoff's fist law:

Total electric currents flowing to a node = Total electric currents leaving the node

$4 + 5 + 2 = 8 + I$

Out of this: $I = 3$ A

Kirchhoff's Second Law: "based on conservation of energy"

The electromotive force of a closed electric circuit expresses the work done or the energy required to transfer a unit electric charge once round the whole circuit.

On the other hand, the potential difference expresses the work done to transfer a unit electric charge across a component in the circuit. $V = I R$

This has been formulated by Kirchhoff in his second law (**Kirchhoff's voltage law**) as follows:

"The algebraic sum of the electromotive forces in any closed loop is equivalent to the algebraic sum of potential differences within that loop"

It can be expressed mathematically as:

$$\sum V_B = \sum I R$$

In analyzing circuits using Kirchhoff's laws, it is helpful to keep in mind the following guidelines.

1- You must assign directions of currents through the different branches. These directions are not the actual directions. Don't worry if you guess incorrectly the direction of a particular unknown current. If the answer resulting from the analysis come out positive, your suggested direction is correct. If negative, the actual current direction in this branch is opposite to the assumed direction.

2- Apply the junction rule (first law) to as many junctions in the circuit as possible.

3- For each closed loop, we assume a certain positive direction and its opposite is negative.

4- Kirchhoff's second law can be applied to more than one closed loop. If it agrees with the assumed current direction considered positive. If it goes the other way round considered negative.

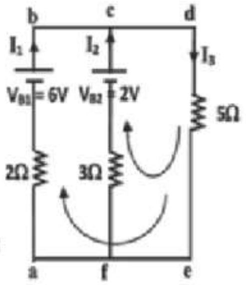
5- The direction of the electromotive force is from the positive pole to the negative pole. If it agrees with the assumed current direction considered positive. If it goes the opposite direction considered negative.

Examples based on Kirchhoff's law

Example (1): In the given circuit calculate:

1- The intensity of current through each branch.
2- The potential difference between the points **a** and **b**

Solution



Assign the directions of current as shown in the circuit.

Applying Kirchhoff's first law at the point (c):

$$I_1 + I_2 = I_3 \quad \rightarrow \quad (1)$$

Applying Kirchhoff's second law to the closed path (loop) (**a b d e a**):

$$\sum V_B = \sum I R$$

$$6 = 2\,I_1 + 5\,I_3 = 2I_1 + 5\,(I_1 + I_2)$$

$$6 = 7\,I_1 + 5\,I_2 \quad \rightarrow \quad (2)$$

Applying Kirchhoff's second law to the closed path (loop) (**c d e f c**):

$$2 = 3\,I_2 + 5\,I_3 = 3I_2 + 5\,(I_1 + I_2)$$

$$2 = 5\,I_1 + 8\,I_2 \quad \rightarrow \quad (3)$$

From equations (2) and (3), the coefficient of one of the two unknown currents is unified by multiplying equation (2) x 5 and equation (3) x 7

$$30 = 35\,I_1 + 25\,I_2$$

$$14 = 35\,I_1 + 56\,I_2$$

Subtracting the last two equations:

$$16 = -\,31\,I_2$$

$$I_2 = -\,0.516\text{ A}$$

The negative sign means that the actual direction of current I_2 is opposite to the assumed direction in figure.

Substituting in equation (3)

$$2 = 5\,I_1 + 8 \times (-\,0.516\,)$$

I_1 =1.226 A

The positive sign means that the assumed direction of current I_1 is correct.

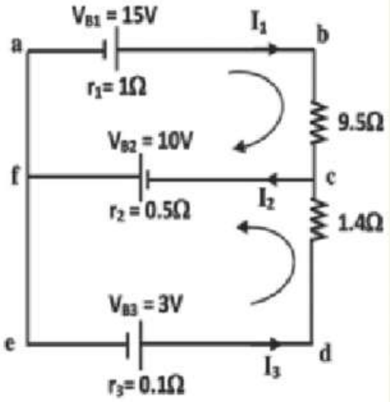
Substituting in equation (1), we find that: I_3 = 0.71 A

To find the voltage across **ab**:

$V = V_B - Ir$

$V = 6 - (1.226 \times 2) = 3.55$ V

Example (2): In the given circuit find the current intensities: I_1, I_2 and I_3



Solution

Applying Kirchhoff's first law at the point (c):

$I_1 + I_3 = I_2 \quad \rightarrow \quad (1)$

Applying Kirchhoff's second law to the closed path (loop) (a b c f a)

$\sum V_B = \sum IR$

$15 + 10 = (1 + 9.5)\ I_1 + 0.5\ I_2$ multiplying x 2

$50 = 21\ I_1 + I_2 \quad \rightarrow \quad (2)$

Applying Kirchhoff's second law to the closed path (loop) **(f c d e f)**

$\sum V_B = \sum IR$

$3 + 10 = 0.5\ I_2 + (0.1 + 1.4)\ I_3$ multiplying x 2

$26 = I_2 + 3I_3 \quad \rightarrow \quad (3)$

From equations (1) and (2),

$50 = 20\,(I_2 - I_3) + I_2 = 22\ I_2 - 21\ I_3 \quad \rightarrow \quad (4)$

Multiplying equation (3) x 7 and adding it to equation (4)

$182 = 7\ I_2 + 21\ I_3$

$50 = 22\, I_2 - 21\, I_3 \quad \rightarrow \quad (4)$

By addition: $232 = 29\, I_2$ $\quad I_2 = 8\ A$

Substituting in equation (2)

$50 = 21\, I_1 + 8$

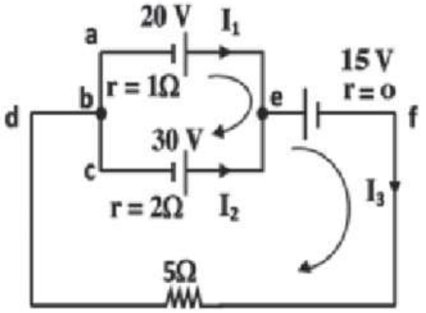
$I_1 = 2\ A$

Substituting in equation (1), we find that: $I_3 = 6\ A$

N.B. All the assigned directions are correct since all current intensities are positive

Example (3): In the circuit shown in figure, find:

1- The intensity of current through each battery.
2- The terminal voltage of each battery.
3- The potential difference across the resistor 5 Ω.



Solution:

Assume directions of current as shown in figure

Applying Kirchhoff's first law at the point (e):

$I_1 + I_2 = I_3 \quad \rightarrow \quad (1)$

Applying Kirchhoff's second law to the closed path (loop) (**a e c b a**)

$\sum V_B = \sum I R$

$20 - 30 = 1 x I_1 - 2 x I_2$

$-10 = I_1 - 2I_2 \quad \rightarrow \quad (2)$

Applying Kirchhoff's second law to the closed path (loop) (**a ef d b a**)

$20 - 15 = 1 x I_1 + 5 x I_3$

$5 = I_1 + 5 (I_1 + I_2)$

$5 = 6I_1 + 5\, I_2 \quad \rightarrow \quad (3)$

Solving equations (2) and (3), by multiplying equation (2) x 5 and equation (3) x 2

$-50 = 5 I_1 - 10 I_2$

$10 = 12 I_1 + 10 I_2$

Adding the two equations:

$-40 = 17 I_1$

$I_1 = -2.35$ A

The direction of the current I_1 is opposite to the assumed direction. i.e. The battery 20 V is in a state of charging.

Substituting in (2), we find that: $I_2 = -3.82$ A i.e. the battery 30 V is in a state of discharge.

And the current $I_3 = 1.46$ A

Terminal voltage of the battery 20 V:

$V_1 = V_B + I r = 20 + (2.35 \times 1) = 22.35$ V

Terminal voltage of the battery 30 V:

$V_2 = V_B - I r = 30 - (3.82 \times 2) = 22.36$ V

$V_3 = 15$V

$V_R = 5 \times 1.46 = 7.3$ V

In a Nutshell

Basic Laws :

- If charge Q flows across a section through a circuit in time t , the current intensity is given by :

$$I = \frac{Q}{t}$$

- If work done to transfer Q (Coulomb) is (W Joule), the voltage (or potential) difference in volts (V) is:

$$V = \frac{W}{Q}$$

- Ohm's law :If the voltage difference across a conductor is V(V) and current I(A) flows then :

$$R = \frac{V}{I} \quad \Omega$$

where R is the resistance of the conductor (also called resistor)

- Resistivity (ρ_e) at a constant temperature:

$$\rho_e = \frac{RA}{\ell}$$

where R is the resistance (Ω), A is the cross sectional area (m^2), and ℓ is the length (m) .

- Conductivity ($\Omega^{-1}m^{-1}$).

$$\sigma = \frac{1}{\rho}$$

- In a series connection :

$$R' = R_1 + R_2 + R_3 + ...$$

- For N equal resistances is series each r, $R' = Nr$

• In a parallel connection:

$$\frac{1}{R'} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

• For N equal resistances each r :

$$R' = \frac{r}{N}$$

• Ohm's law for a closed circuit:

$$I = \frac{V_B}{R + r}$$

where V_B is the emf of the source, r is its internal resistance and R is the external resistance.

Kirchhoff's First Law

The sum of currents flowing into a node in electric circuit is equal to the sum of currents flowing out of that node

$$\sum I = 0$$

Kirchhoff's Second law

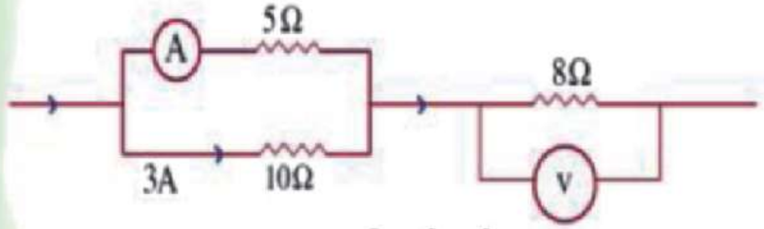
The algebraic sum of the electromotive forces in any closed loop is equivalent to the algebraic sum of potential differences in that loop

$$\sum V_B = \sum IR$$

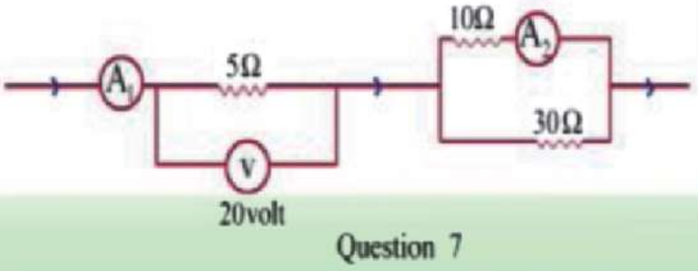
Questions and Drills

I) Complete

1) When a current of intensity 3A passes through a point in an electric circuit, the electric charge passing through one minute equals..........
2) The voltage difference in volt required to let a current of 3A pass through a 6 Ω resistor equals ....
3) If the voltage difference across a 2Ω resistor is 6V, the current intensity is ....
4) If two equal resistances1Ω each are connected in series, the equivalent resistance is .... ,but if they are connected in parallel, it is ....
5) The emf is measured in the same units as ....



Question 6



Question 7

6) In the circuit shown :

a) the ammeter reading is ....

b) the voltmeter reading is ....

7) In the circuit shown

a) the ammeter reading A_1 is ....

b) the ammeter reading A_2 is ....

II) Choose the right answer:

Four lamps 6Ω each are connected in parallel. The combination is connected to a 12V battery with a negligible internal resistance:

1) The current in the battery equals..........

a) 8A b) 6A c) 4A d) 2A e) 72A

2) The total charge leaving the battery in 10s is...............

a) 80C b) 60C c) 40C d) 20C e)2C

3) The current in each lamp is ....

a) $\frac{3}{2}$ A b) 8A c) $\frac{3}{2}$ A d) 1A e) 2A

4) The voltage difference across each lamp is..........

a) 3V b) 12 V c) 6 V d) 2 V e) 4 V

5) The total resistance of the four equal lamps is...........

a) $\frac{2}{3}$ Ω b) 24Ω c) $\frac{3}{2}$ Ω d) 6Ω e) 12Ω

6) If the 4 lamps are connected in series, the total resistance is.............

a) $\frac{3}{2}$ Ω b) 24Ω c) $\frac{2}{3}$ Ω d) 6Ω e) 12Ω

III) Essay Questions:

1) Show how to prove that the equivalent resistance of 3 resistors connected in series is given by :

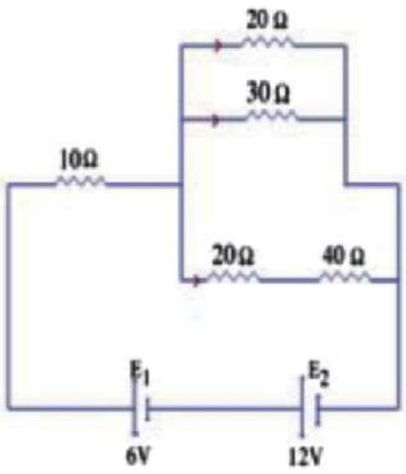
$R = R_1 + R_2 + R_3$

2) Show that the reciprocal of the equivalent resistance of 3 resistors connected in parallel is equal to the sum of the reciprocals.

3) What are the factors determining the resistance of a conductor ?

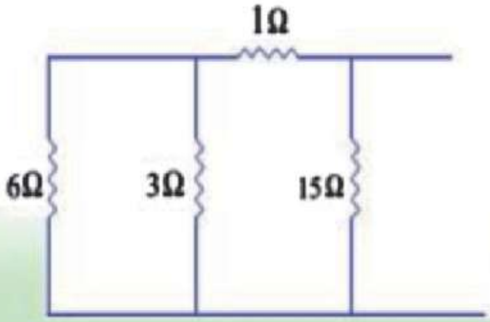
IV) Drills :

1) Calculate the total resistance in the circuit shown and also the total current intensity if the internal resistance of each cell is 2Ω. (0.75 A, 20Ω)



Drill 1

2) Determine the equivalent resistance of a bunch of the resistors shown. (2.5Ω)



Drill 2

3) The circuit shown in Fig (1 – 5) consists of a 15 V battery, an external resistance 2.7Ω and a switch. If the internal resistance of the battery is 0.3Ω, determine :

a) the reading of the voltmeter when the switch is open, assuming that the voltmeter resistance is infinite. (15 V)

b) the reading of the voltmeter when the switch is closed. (13.5)

4) A student wound a wire of a finite length as a resistor. Then, he made another of the same material but half the diameter of the first wire and double the length. Find the ratio of the two resistances. (1:8)

5) A copper wire 30 m long and $2x10^{-6}m^2$ cross sectional area has a voltage difference of 3V across. Calculate the current if the copper resistivity is 1.79×10^{-8} Ω.m

(11.17 A)

6) A 5.7Ω resistor is connected across the terminals of a battery of 12Ω emf and 0.3Ω internal resistance. Calculate:

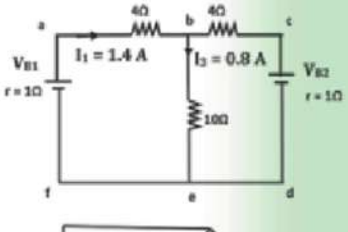
a) the current in the circuit . (2. A)

b) the voltage difference across the resistor. (11.4 V)

7) Analyze the given circuit in the opposite diagram using Kirchhoff's laws to find:

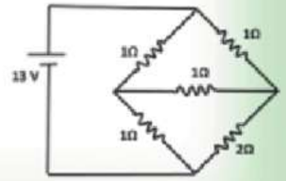
a) V_{B1} and V_{B2}
b) The voltage drop across eb

Answers: (V_{B1}= 15 V, V_{B2} = 5 V and V_{eb} = 8 V)

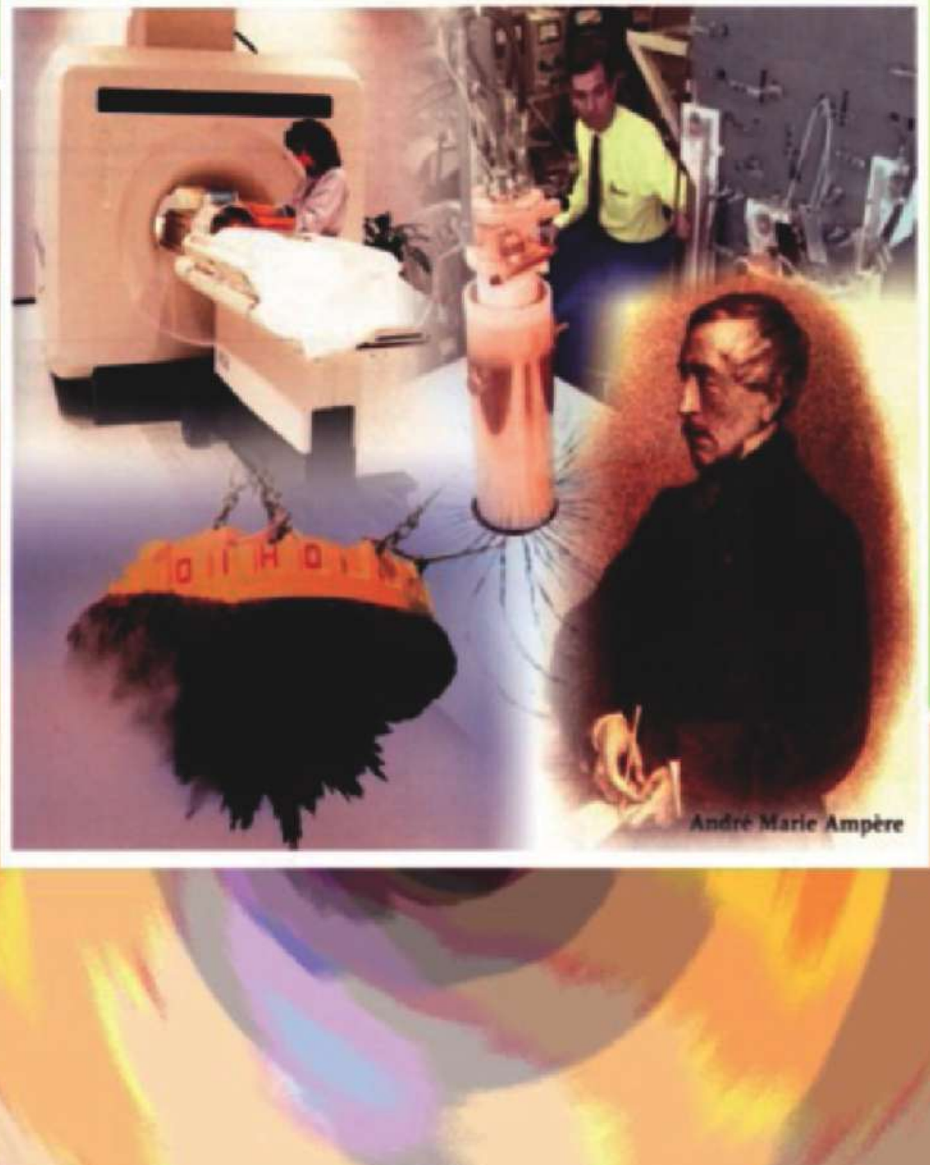


8) Find the equivalent resistance of the given resistance network using Kirchhoff's laws.

Answer: 1.18 Ω



Dynamic Electricity and Electromagnetism



UNIT 2

Chapter 2 : Magnetic Effects

Overview

In 1819, Hans Christian Oersted- a Danish physicist-brought a compass near a wire carrying an electric current. He noticed that the compass was deflected. When he turned the current off, the compass assumed its original position. The deflection of the compass-while current was flowing through the wire- indicated that it was being acted upon by an external magnetic field.This discovery started a chain of events that has helped shape our industrial civilization.

In this unit we are going to study the magnetic field of current- carrying conductors in the form of:

a) a straight wire. b) a circular loop. c) a solenoid.

Magnetic field due to current in a straight wire:

We can examine the pattern of the flux density surrounding a long straight wire carrying a direct current using iron filings sprinkled on a paper surrounding the wire in a vertical position.It will be noted that they become aligned in concentric circles around the wire, as shown in Fig (2 -1).

Oersted

Fig (2 – 1) Pattern of iron filings around a wire carrying current

The figure shows that the circular magnetic flux lines are closer together near the wire and farther apart from each other as the distance from the wire increases.

As the electric current in the wire increases, the iron filings rearrange themselves after gently tapping the board such that the concentric circles become more crowded.

This indicates that the magnetic field due to the electric current passing through a straight wire increases with increasing the current intensity and vice verse.

The magnetic flux density **B** measured in Weber/m^2 or Tesla ($B = \frac{\phi_m}{A}$ where ϕ_m is the magnetic flux, A is the area) a point near a long straight wire carrying current I can be determined using the formula:

$$B = \frac{\mu I}{2 \pi d} \qquad (2\text{-}1)$$

This relation is called Ampere's circuital law, where d is the normal distance between the point and the wire, and μ is the magnetic permeability of the medium (in air it is $4\pi \times 10^{-7}$ Weber/A.m.)Thus, B is inversely proportional to d and directly proportional to I. This is why it is advisable to live away from high voltage towers.

Ampere's right hand rule:

To determine the direction of the magnetic field resulting from an electric current in a wire, imagine that you grasp the wire with your right hand such that the thumb points in the direction of the current. The rest of the fingers around the wire give the direction of the magnetic field due to the current (Fig 2-2).

Fig (2 – 2)
Right hand rule

Examples:

Determine the magnetic flux density at a distance of 10cm in air from the center of a long wire carrying a current of 10A.

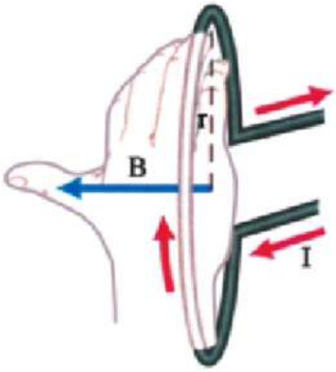
Solution:

$$B = \frac{\mu I}{2\pi d} = \frac{4\pi \times 10^{-7} \times 10}{2\pi \times 0.1} = 2 \times 10^{-5} \text{ Tesla}$$

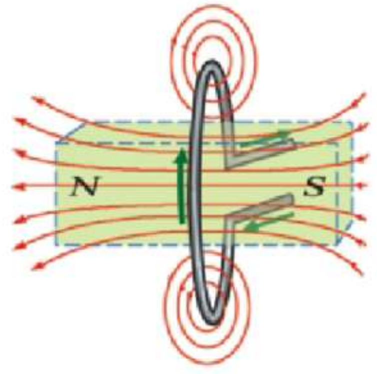
Magnetic field due to current in a circular loop:

If a wire is bent into a circular loop and carries current as shown in Fig. (2 -3), the magnetic field is very similar to that of a short bar magnet. One face of the loop - where the direction of the current is clockwise upon looking at it- behaves as a south pole, and the other face- where the direction of the current is counter clockwise- behaves as a north pole.

a)field pattern



b) direction of the magnetic field at the center of the loop



c) polarity of the loop

Fig (2 – 3)

Magnetic field due to a circular loop

To study the magnetic field due to a circular loop (or a coil),iron filings are sprinkled on the board as shown in Fig (3 -10). Tapping it gently, the filings arrange themselves as shown in figure, from which we can notice that:

1. the flux lines near the center of the loop are no longer circular.
2. the magentic flux density changes from point to point.
3. the magnetic flux lines at the center of the loop are straight parallel lines perpendicular to the plane of the coil. This means that the magnetic field in this region is uniform.

The flux density at the center of a circular loop of N turns and radius r carrying current I is given by :

$$B = \frac{\mu N I}{2r} \quad (2\text{-}2)$$

From this relation, the magnetic flux density at the center of a circular loop depends on three parameters:

1. number of turns of the circular loop where $B \propto N$.
2. current intensity passing through the circular loop where $B \propto I$.
3. radius of circular loop where $B \propto \frac{1}{r}$.

- Right-hand screw rule:

To determine the direction of the magnetic field at the center of a circular loop or coil, imagine a righthand screw being screwed to tie along the wire in the direction of the current. The direction of fastening of the screw gives the direction of the magnetic flux at the center of the loop (Figs. 2-4, 2-5)

Thus, a circular loop carrying current acts as a magnetic dipole.

It is to be noted that no single poles exist in nature. They always exist in N - S pairs.

Thus circular loop carrying current may be considered a solid disc having two circular poles as a bar magnet (Fig 2 -3)

Fig (2 – 4)
Right hand screw direction of screwing.

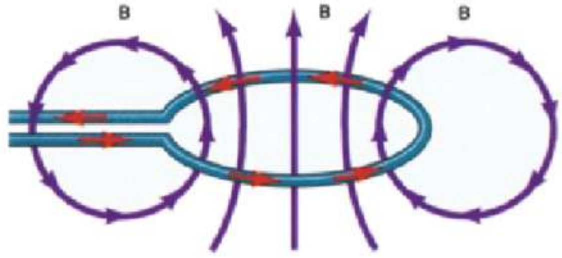


Fig (2 – 5)
A circular loop carrying current in the direction of screwing.

Examples:

Determine the magnetic flux density at the center of a circular loop of radius 11cm carrying a current of 1.4 A. if the wire loop consists of 20 turns and $\mu_{air} = 4\pi \times 10^{-7}$ Weber/Am

solution:

$$B = \frac{\mu NI}{2r} = \frac{4\pi \times 10^{-7} \times 20 \times 1.4}{2 \times 0.11}$$

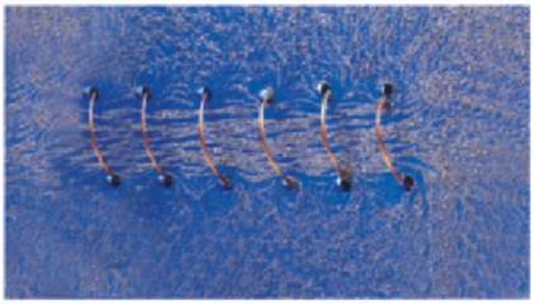
$$= \frac{4 \times 22 \times 10^{-7} \times 20 \times 1.4}{7 \times 2 \times 0.11} = 16 \times 10^{-5} \text{ Tesla}$$

Magnetic field due to current in a solenoid:

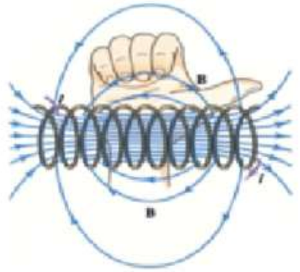
When an electric current is passed through a solenoid (a long spiral or cylindrical coil) as shown in Fig(2-6), the resultant magnetic flux is very similar to that as a bar magnet. As shown in Fig(2-6A), the magnetic flux lines make a complete circuit inside and outside the coil,i.e., each line is a closed path. The side at which the flux emerges is the north pole, the other side where the magnetic flux reenters is the south pole. The magnetic flux density in the interior of a solenoid carrying an electric current depends on :

1) the current intensity passing through the coil where $B \propto I$.

2) the number of turns per unit length where $B \propto n$:



a) field pattern



b) polarity of the coil using Ampere's right hand rule.

Fig (2 – 6)

Magnetic field due to a solenoid carrying current

$$\therefore B \propto nI$$

$$B = \mu nI$$

where μ is the permeability of the core material. In this case, it is air

This relation may be rewritten as follow:

$$B = \mu \frac{N}{\ell} I \qquad (2\text{-}3)$$

Where N is the number of tuns of a solenoid of length ℓ. To determine the polarity of a solenoid carrying current we have the right screw rule considering that the solenoid consists of concentric turns (Fig 2-6b).

Examples:

1) A long solenoid has 800 turns and carries a current of 0.7A. Find the magnetic flux density at a point on the axis of a solenoid knowing that its length is 20 cm.

Solution :

$$B = \frac{\mu N I}{\ell} = \frac{4 \times 22 \times 10^{-7} \times 800 \times 0.7}{7 \times 0.2}$$

$$= 3.52 \times 10^{-3} \text{ Tesla}$$

2) A solenoid is constructed by winding 800 turns of wire on a 20 cm iron core. What current is required to produce a flux density of 0.815 Tesla at the center of the solenoid ? The permeability of iron is $1.63\ 10^{-2}$ Weber/Am

Solution :

$$B = \mu \frac{NI}{\ell}$$

$$0.815 = \frac{1.63 \times 10^{-2} \times 800 \times I}{0.2}$$

$$I = \frac{0.815 \times 0.2}{1.63 \times 10^{-2} \times 800} = 0.0125 \text{ A}$$

Force due to magnetic field acting on a straight wire carrying current.

If we place a straight wire carrying current between the poles of a magnet,a force results which acts on the wire and is perpendicular to both the wire and the field (Fig 2-7). The direction of the force is reversed if we reverse the current or the magnetic field. In all cases, the force is perpendicular to both electric current and the magnetic field. In case the wire is allowed to move due to this generated force, the direction of motion is perpendicular to both the electric current and the magnetic field. The direction of the force with which a magnetic field acts on a current- carrying wire perpendicular to the field can be obtained by applying Fleming's left hand rule.

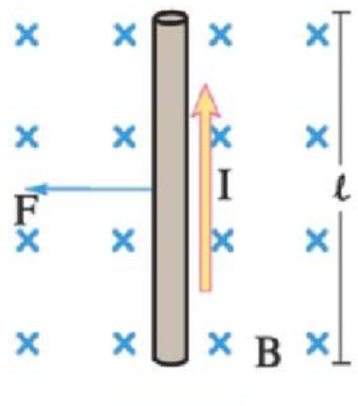


Fig (2 – 7)
Force due to a magnetic field acting on a straight wire carrying current, mark"x" denotes the direction into the paper.

Fleming's left hand rule

Form your left hand fingers as follows: the pointer and thumb perpendicular to each other and to the rest of the fingers. Make the pointer point to the direction of the magnetic flux, and the rest of the fingers- except the thumb- in the direction of the current. Then, the thumb points to the magnetic force or motion (Fig 2-8).

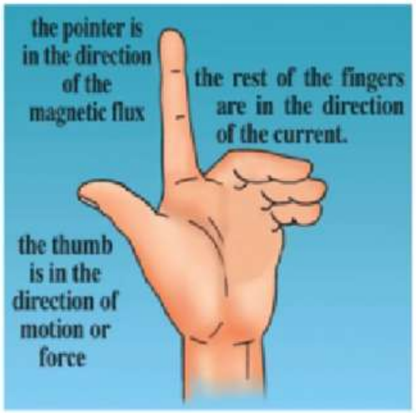


Fig (2 – 8)
Fleming's left hand rule.

It is found that the force acting on a wire carrying current flowing perpendicularly to a

magnetic field depends on the following factors:

1) the length of the wire ℓ, as the force is directly proportional to the length of the wire $F \propto \ell$

2) the current intensity I, as the force is directly proportional to the current in the wire I i.e. $F \propto I$.

3) the magnetic flux density B, as the force is directly proportional to the magnetic flux density. Thus: $F \propto BI\ell$

$$\therefore F = const \times BI\ell$$

The unit for magnetic flux density is Tesla. It generates a force of 1 N on 1 m long wire carrying a current of 1A.

$Weber/m^2 = N/Am$.

$$\boxed{F = BI\ell} \quad (2\text{-}4)$$

$$B = \frac{F}{I\ell}$$

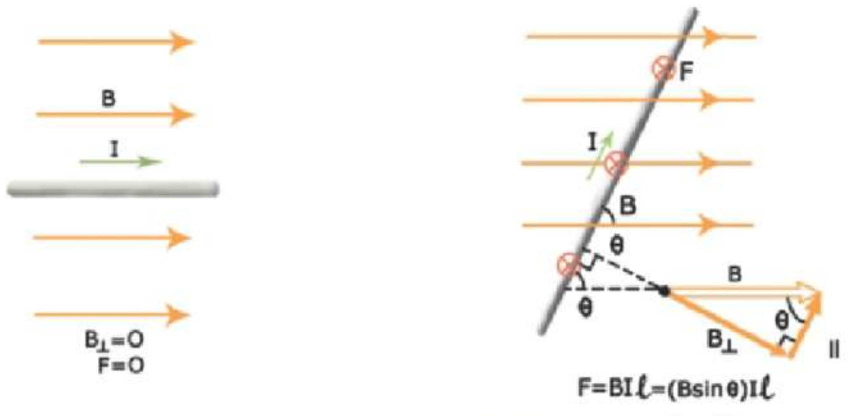
Tesla: The unit of the magnetic flux density

It is the magnetic flux density, which will exert a force of one newton on a current-carrying wire of one meter length perpendicular to the field when the current is one ampere. In general, if a wire of length ℓ makes an angle θ with the field "B" (Fig 2-9), then B can be analyzed into two compenents,one parallel to the current in the wire namely,B cos θ, and the other perpendicular to the direction of the current in the wire namely, B sin θ. In this case:

$$F = BI\ell \sin\theta$$

From this relation, we see that the force F vanishes when $\theta = 0$,i.e, when the wire and the magnetic field are parallel.

You can imagine what the direction of the force will be in different cases. The mark ⊙ means out of the page, and the mark ⊗ means into the page.



a) the force vanishes when θ = 0 (wire and magnetic field are parallel)

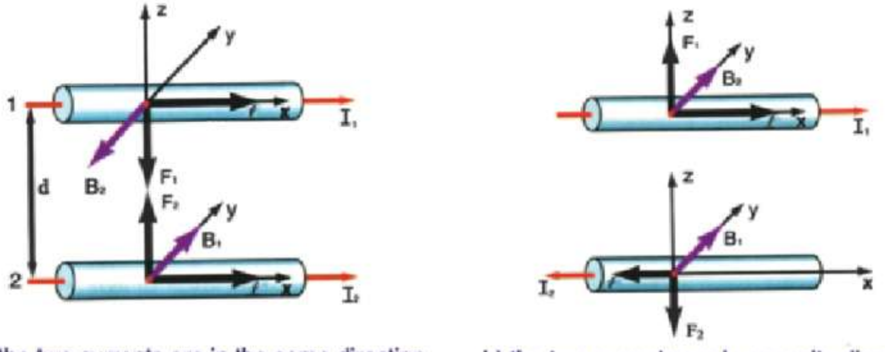
b) a force exists for θ other than zero

Fig (2 – 9)

A wire carrying current in a direction inclinded by an angle θ to the magnetic field.

The force between two parallel wires each carrying current.

When a current I_1 passes in a wire and a current I_2 passes in another parallel wire, a force results between the two wires. This force is attractive if the two currents flow in the same direction. The force is repulsive if the two currents flow opposite to each other. We can calculate this force as follows:



a) the two currents are in the same direction.

b) the two currents are in opposite directions.

Fig (2 – 10)

Force between two parallel wires each carrying current

$$B_2 = \frac{\mu_o I_2}{2\pi d}$$

$$F_1 = B_2 I_1 \ell$$

$$= \left(\frac{\mu_o I_2}{2\pi d}\right) I_1 \ell$$

$$F_1 = \frac{\mu_o I_1 I_2 \ell}{2\pi d}$$

Examples:

1) A 30cm long wire supports a current of 4A in a direction perpendicular to a magnetic field. If the force developed on the wire is 6 N, find the magnetic flux density.

Solution :

$$F = BI\ell$$

$$6 = B \times 4 \times 0.3$$

$$B = \frac{6}{4 \times 0.3} = \frac{6}{1.2} = 5 \text{ Tesla}$$

2) If the wire in the previous example makes an angle 30° with respect to the field, find the force acting on the wire.

Solution :

$$F = BI\ell \sin\theta$$

$$= 5 \times 4 \times 0.3 \times \frac{1}{2} = 3N$$

Force and Torque acting on a rectangular coil carrying current placed in a magnetic field.

If we have a rectangular coil abcd (Fig 2-11), whose plane is parallel to the lines of a uniform magnetic flux,both ad and bc are parallel to the flux lines. The force acting on each wire is zero. As to both ab and cd, they are perpendicular to the flux lines.They will be acted upon by two forces equal in magnitude and opposite in direction and are parallel, each equal to $F=BI\ell_{cd}$,seperated by a perpendicular distance ℓ_{ad} or ℓ_{bc} Thus, the coil is acted upon by a torque which will cause the coil to rotate around its axis.

The magnitude of the couple (torque) is equal to the force magnitude times the perpendicular spacing between the two equal forces:

$$\tau = BI \ell_{cd} \ell_{bc} = BIA$$

where "A" is the area of the rectangle $A=\ell_{bc} \ell_{cd}$. If the rectangle consists of N turns,the total τ (read Taw) becomes :

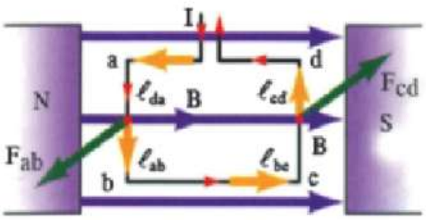
$$\boxed{\tau = BIAN = B|\vec{m_d}|} \quad (2\text{-}5)$$

where $|\vec{m_d}|$= IAN is the magnetic dipole moment which is a vector emanating from the north pole of the coil perpendicularly to the area of the coil in the direction of advancing of a right hand screw, which is the direction of flow of the current. Thus, if the coil is perpendicular to the flux lines, $\vec{m_d}$ is along the flux lines and the couple is zero. If the plane of the coil is inclined with respect to the magenetic flux at an angle (Fig 2-11), then :

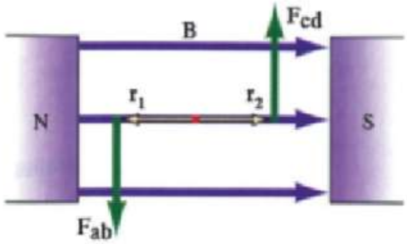
$$\boxed{\tau = BIAN \sin\theta} \quad (2\text{-}6)$$

where θ is the angle between the normal to the plane of the rectangle (which is the direction of the magnetic dipole moment $\vec{m_d}$ and the magnetic flux lines).

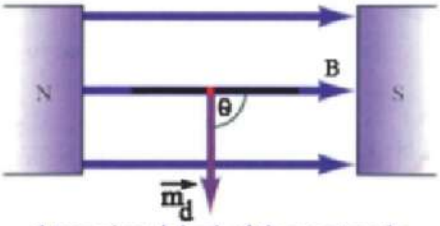
The concept of a couple in a coil carrying a current is used in many instruments and also in electric motors .



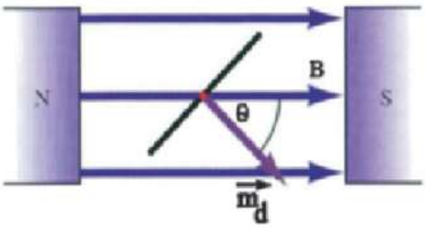
a) the coil is parallel to the magnetic field.



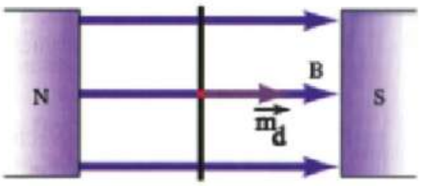
b) top view (plan)of the rectangle when the coil is parallel to the field.



c) top view (plan) of the rectangle when the magnetic dipole moment is perpendicular to the field.



d) top view (plan) of the rectangle when the magnetic dipole moment makes an angle θ with the field.



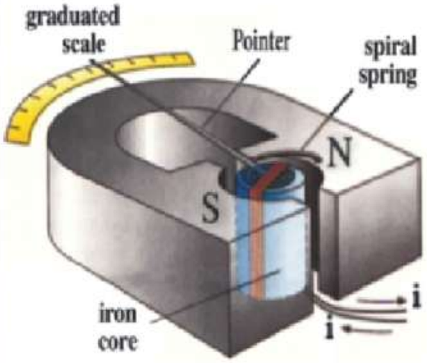
e) top view (plan) when the rectangle is perpendicular to the field or the magnetic dipole moment is parallel to the field and the couple is zero.

Fig (2 – 11)
A torque acting on a coil carrying a current

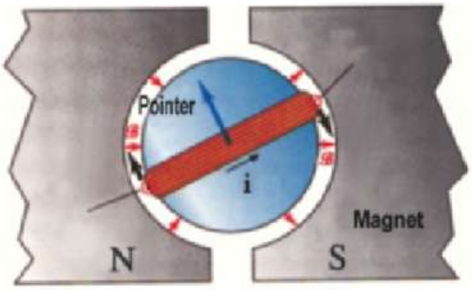
Applications: Measuning Instuments

The sensitive moving coil galvanometer

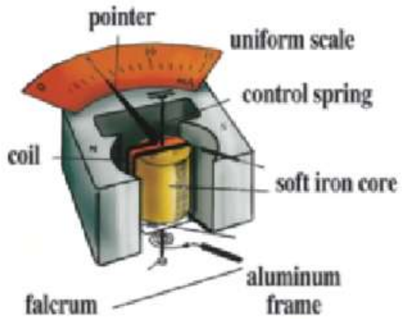
A sensutive moving coil galvanometer is an apparatus used to detect very weak currents in a circuit, measure their intensities and determine their polarities. Its principle of operation depends on the torque that is generated in a current -carrying coil moving in a magnetic field.



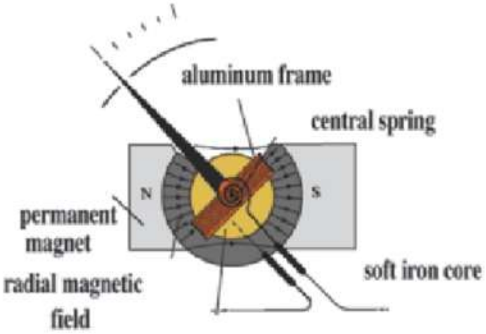
a) a simplified view of a galvanometer when the pointer is in the middle of the graduated scale



b) top view



c) a galvanometer converted to a milliammeter



d) top view

(Fig 2 – 12)
A moving coil galvanometer

The essential parts of this device are shown in Fig(2 -12). It consists of a rectangle of a thin wire coil wrapped around a light aluminum frame mountend on a soft iron core. The frame is pivoted on agate bearings. The assembly rotates between the poles of a U shaped (horse shoe) magnet. Its rotational motion is restrained by a pair of spiral control springs, which also serve as current leads to the coil. Depending upon the direction of the current being measured, the coil and pointer rotate either in clockwise or counterclockwise direction. The permanent magnet's poles are curved so that the magnetic flux lines are radially directed. Thus, the magnetic flux density is constant and perpendicular to the side of the rectangle irrespective of the angle of the coil. the deflection of the pointer is proportional to the current in the coil.

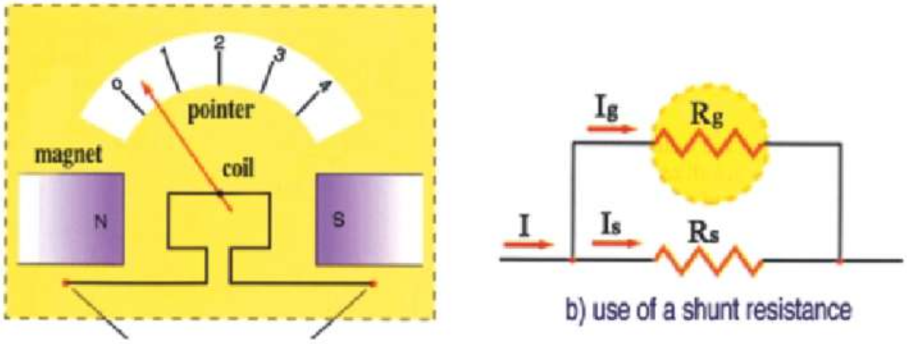
The current flows in the coil from the right side upwards, and emerges from the other side. Then the magnetic force generates a torque which makes the coil rotate clockwise. The pointer deflects until it settles at a certain reading when the torque is balanced with the spring torsion which is counterclockwise. Thus, at balance, we can read the current value. When the current is reversed, the pointer deflects in the opposite direction.

The galvanometer sensitivity:

The galvanometer sensitivity is defined as the scale deflection per unit current intensity passing through its coil i.e, sensitivity = $\frac{\theta}{I}$ degree/micro ampere (deg/μA) .

Direct current (DC) ammeter :

An ammeter is a device which- through calibrated scales- is used to measure directly the electric current. A galvanometer is an ammeter of limited range due to its moving coil sensitivity. To extend the range of the galvanometer, it is necessary to add a very low resistance, called a shunt R_s to be connected in parallel with the galvanometer coil R_g as shown in Fig (2 -13).



a) a DC ammeter is a galvanometer whose pointer deflects in one direction

b) use of a shunt resistance

Fig (2 – 13)
The DC ammeter

Placing the parallel shunt assures that the ammeter as a whole will have a very low resistance, which is necessary if the current in the circuit is to be unaltered after connecting the ammeter in series.

Most of the current in the circuit passes through the shunt R_s, while only a small current I_g passes in the galvanometer coil R_g. If the maximum current to be measured is I, which is the full scale deflection (FSD), then

$$I = I_g + I_s$$
$$I_s = I - I_g$$

Because R_s and R_g are connected in parallel, the voltage difference across each is the same.

$$I_s R_s = I_g R_g$$
$$R_s = \frac{I_g R_g}{I_s}.$$

The two equations can be solved simultaneously to find R_s. Thus,

$$\boxed{R_s = \frac{I_g R_g}{I - I_g}}$$

Example

A certain galvanometer has a resistance 2Ω, and a current of 5mA is required for full-scale deflection. What shunt resistance must be used to convert the galvanometer to an ammeter whose maximum range is10 A?

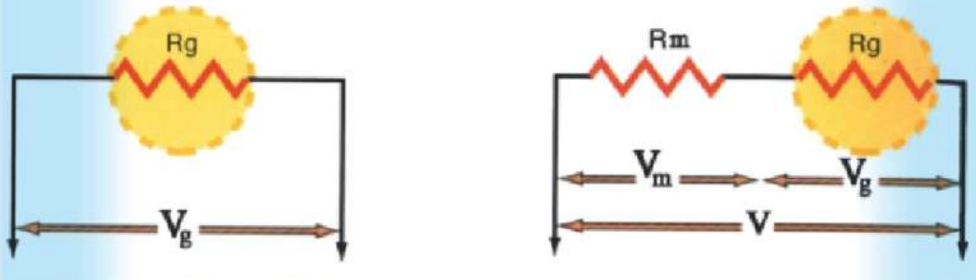
Solution

$$R_s = \frac{I_g R_g}{I - I_g} = \frac{0.005 \times 2}{10 - 0.005}$$

$$R_s = \frac{0.01}{9.995} = 0.001\ \Omega$$

Direct current(DC) voltmeters :

A voltmeter is a device for measuring the potential difference across two points in an electric circuit.We shall discuss in this section how the galvanometer may be used to measure voltage. The positive terminal of the voltmeter must to connected to the positive terminal in the circuit.If the voltage difference is switched, the voltmeter connection must be inverted.The potential difference across a galvanometer is extremely small even when a large scale deflection occurs.Thus,if a galvanometer is to be used to measure the



a) the small coil resistance will not alter the value of the voltage to be measured in the circuit

b) the use of a multiplier resistor makes the resistance of the voltmeter high so it will not affect the voltage to be measured in the circuit

Fig (2 –14)
DC voltmeter

voltage,it must be converted to a high-resistance instrument.The voltmeter must draw a negligible current, so that it will not affect the voltage drop to be measured.To do this,a large multiplier resistor is connected in series with the galvanometer as shown in Fig. (2-14).The voltmeter is connected parallel across the two points between which the voltage difference is to be measured. Let us call the resistance of the galvanometer coil R_g and the multiplier resistance R_m which is connected in series parrallel with R_g. The maximum current that passes through it is I_g, which is the current needed for the full scale deflection (FSD) voltage V.

The voltage difference across the coil is :

$$V_g = I_g R_g$$

The maximum voltage drop to be measured is:

$$V = I_g R_g + I_g R_m = V_g + I_g R_m$$

$$\boxed{R_m = \frac{V - V_g}{I_g}} \quad (2\text{-}8)$$

Example

A galvanometer has an internal resistance of 0.1Ω and gives a full scale deflection for a current of 1mA. Calculate the multiplier resistance necessary to convert this galvanometer to a voltmeter whose maximum range is 50V.

Solution

$$V_g = I_g R_g = 0.001 \times 0.1 = 1 \times 10^{-4}\ V$$

$$R_m = \frac{V - V_g}{I_g} = \frac{50 - 1 \times 10^{-4}}{1 \times 10^{-3}}$$

$$= 49999.9\ \Omega$$

The total resistance of the voltmeter is :

$$R_{total} = 49999.9 + 0.1 = 50000\ \Omega$$

Ohmmeter

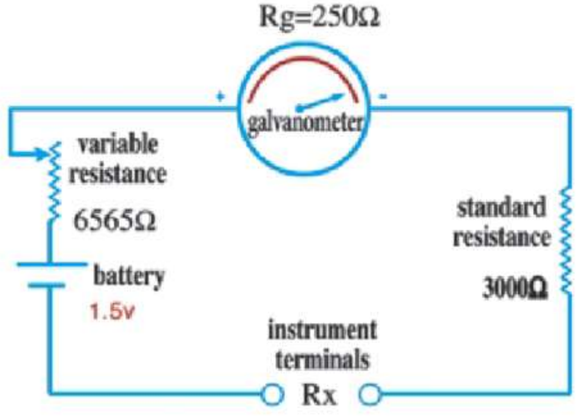


Fig (2 – 15)
A circuit for calibrating an ohmmeter

Measuring a resistance depends on measuring the current passing through it by an ammeter and the voltage drop across it by a voltmeter. If the current is I and the voltage drop is V, the resistance R from Ohm's law is R =V/I

If the voltage is fixed and known, we may remove the voltmeter from the circuit and calibrate the galvanometer to give the value of the resistance directly (Fig 2 -15).As the resistance is increased, the current in the circuit decreases,and consequently, the galvanometer reading.The Ohmmeter shown (Fig 2 -15) is actually a microammeter which reads 400μA as a full scale deflection (FSD).Its resistance is 250Ω connected in series with 3000Ω, a variable resistance whose maximum value is 6565Ω, and a 1.5 V battery of negligible internal resistance.When we short circuit (sc) the terminals of the instrument (R_X =0), current flows in the circuit.For this current to give FSD, the resistance in the circuit must be: $\frac{1.5}{400 \times 10^{-6}} = 3750\ \Omega$

The variable resistance must be adjusted to give FSD, when the variable resistance is 500 since 250+3000+500=3750Ω.

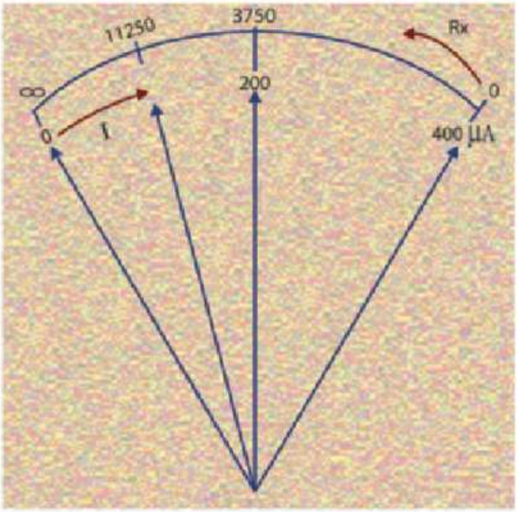
Now, if the unknown resistance is introduced into the circuit, the current flowing will be less, and the pointer will deflect short of FSD.

Thus, we may calibrate the instrument in terms of the resistance to be measured. If R_X = 3750Ω, the current in the instrument is 200 μA, which is 1/2 the maximum current, and hence the deflection is 1/2 FSD.

If the resistance is doubled, i.e., 7500Ω., the deflection will be $\frac{1}{3}$ FSD. For three times the total resistance, i.e., 11250Ω, the deflection will be $\frac{1}{4}$ FSD corresponding to a current of 100μA. It is to be noted that the graduated scale used to measure the resistance (Fig 2-16) is opposite to the graduated scale for the current .

This means that the maximum deflection corresponds to zero resistance (short circuit or sc). As the resistance increases, the deflection decreases.

It is to be noted also that the scale is not linear. The spacings between the readings of the scale to the right are further apart than the readings to the left.



$R_X(\Omega)$	IμA
0	400
3750	200
11250	100
∞	0

Fig (2 – 16)
An ohmmeter has a nonlinear graduated scale

The instruments using a point, are called analog instruments. A combined instrument called multimeter can be switched around to measure voltage, curent and resistance (Fig 2-17).

Another set of instruments now exist which depend on reading numerals, denoting voltage, current a resistance on a small LCD (liquid crystal display) without the need for a pointer. Such instruments are called digital multimeters (Fig 2-18).

They depend on digital electronics (Chapter 8). All the above instruments measure voltage or current in one direction (DC). Therefore, they are called DC/multimeters. But if the current or voltage is AC, the instrument used is called AC/ multimeters.

Fig (2 – 17)
Analog multimeter

Fig (2 – 18)
Digital multimeter

In a Nutshell

- Definitions and Basic Concepts:

- A megnetic field is produced around a current-carrying wire.
- The intensity of the magnetic field produced around a current-carrying wire, increases, by :
  a) getting closer to the wire.
  b) increasing the current.
- The direction of the magnetic field produced around a current-carrying straight wire is determined by Ampere's right-hand rule.
- The lines of force around a current-carrying wire forming a circular loop, resemble to a great extent those of a short bar magnet.
- The magnetic flux density at the center of a current-carrying circular loop depends on:
  a) the number of loop turns.
  b) the current intensity in the loop.
  c)the radius of the loop.
- The direction of the magnetic field at the center of a current-carrying loop is determined by the right-hand screw rule.
- The magnetic field produced by a current flowing through a solenoid (coil of several closely spaced loops) resembles to a great extent that of a bar magnet.
- The magnetic flux density at any point on the axis of a current-carrying a solenoid depends on :
  a) the current intensity.
  b) the number of turns per unit length.
- Right-hand screw rule is used to determine the polarity of a solenoid carrying a current.
- The unit of magnetic flux density is Web / m^2, (Tesla or N/Am).
- The force exerted by a magnetic field on a current-carrying wire placed in the field depends on:

a) the length of the wire.

b) the current intensity.

c) the magnetic flux density.

d) the angle between the wire and the direction of the magnetic field.

- A moving coil galvanometer is an instrument used to detect, measure and determine the polarity of very weak electric currents.
- The operation of a moving coil galvanometer is based on the torque acting on a current loop in the presence of a magnetic field.
- The sensitivity of a galvanometer is defined as the scale deflection per unit current intensity flowing through its coil.
- The ammeter is a device which is used through a calibrated scale to measure directly the electric current.
- To extend the range of the galvanometer, a low resistor known as a shunt is connected in parallel with the coil of the galvanometer.
- The total resistance of the ammeter (with the shunt) is very small, therefore, it does not appreciably change the current to be measured in a closed circuit.
- The voltmeter is a device used to measure the potential difference across two points of an electric circuit. It is basically a moving coil galvanometer having a very high resistance called a multiplier resistance connected in series with its coil.
- Since the total resistance of the voltmeter is very great, it does not affect much the flow of current through the element across which it is connected to measure its potential difference.
- The ohmmeter is an instrument which is used to measure an unknown resistance.
- An ohmmeter is basically a microammeter connected in series with a constant cell resistance, a variable resistance and a 1.5 volt battery. If its terminals are in contact (sc), the pointer gives full-scale deflection (FSD). If a resistor is inserted between its terminals, the current flowing decreases. Hence, the pointer's deflection decreases, and indicates directly the value of the inserted resistor through a calibrated scale.

Basic Laws

- The magnetic flux density "B" at a point which is d (m) away from a wire carrying current I (A) is determined by the relation $B = \frac{\mu I}{2\pi d}$ Weber/m^2 (or Tesla)

- The magnetic flux density B at the center of a circular loop of radius r, carrying current I and of N turns, is :

$$B = \frac{\mu N I}{2r} \text{ (Tesla)}$$

- The magnetic flux density at any point on the axis of a solenoid of length ℓ, number of turns N and carrying current I, is :

$$B = \frac{\mu I N}{\ell} \text{ (Tesla)}$$

- The magnetic force acting on a wire of length ℓ carrying current I and placed in a magnetic field of B flux density is :

$$\sin\theta \, \ell \, F = B I$$

where θ is the angle between the wire and the direction of the magnetic field.

- The torque acting on a rectangular loop of face area A, number of turns N, carrying current I and placed parallel to a magnetic field of flux density B is :

$$\tau = B I A N = |\vec{m}_d| B \quad \text{(Nm)}$$

where $|\vec{m}_d| = IAN$. The magnetic dipole moment $\vec{m}_d$ is a vector prependicular to the plane of the coil.

- The value of the shunt of an ammeter is given from the relation: $R_s = \frac{I_g R_g}{I - I_g}$,

where R_s is the shunt resistance, I_g is the maximum current in the galvanometer coil. R_g is the resistance of the galvanometer coil, and I is the full scale deflection (FSD) current.

- The multiplier resistance R_m in a voltmeter is given by the relation. $R_m = \frac{V - V_g}{I_g}$,

where V is the FSD voltage, V_g is the voltage drop across the galvanometer coil and I_g is the current flowing in the galvanometer which corresponds to full scale deflection (FDS).

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Questions and Drills

I) Essay questions:

1) State the parameters on which the magnetic flux density depends in each of the following cases:

   a) around a long current-carrying straight wire.

   b) at the center of a circular loop that carries current.

   c) at any point on the axis of a current-carrying solenoid.

2) What are the parameters affecting the magnitude of the force with which a magnetic field acts on a current-carrying wire placed at right angles to the field?

3) Prove that the force F acting on a long wire B of length ℓ carrying current I and placed at right angles to a magnetic field of flux density B is determined by the relation: $F = B I \ell$

4) Prove that the torque τ acting on a loop of face area A, number of turns N, carrying a current I and placed parallel to a magnetic field of B flux density is $\tau = B I A N$

5) Describe with the aid of a labelled diagram the construction of the sensitive galvanometer and explain its basic operation.

6) Explain how the sensitive galvanometer is converted to be used as an ammeter. Deduce the required relation.

7) Explain how the sensitive galvanometer is converted to be used as a voltmeter. Deduce the required relation.

8) Give reasons for :

   a) mounting a soft iron cylinder inside the coil of the galvanometer.

b) the coil of the moving coil galvanometer is attached to a pair of spiral springs.

c) when the moving coil galvanometer is used as a voltmeter, a resistor of high resistance is connected in series with its coil.

d) an ammeter is connected in series with a circuit, but the voltmeter is connected parallel to it.

e) connecting a constant resistor inside the ohmmeter.

f) the cell connected to the ohmmeter should have a constant emf.

9) What is meant by each of: potential multiplier and shunt? What is the use of each? Deduce the rule related to each.

10) Explain how you can use the moving coil galvanometer to measure each of the electric current, the electromotive force and the electrical resistance.

II) Drills:

1) A coil of cross sectional area 0.2 m^2 is placed normal to a regular magnetic flux of density 0.04 Weber/m^2. Calculate the magnetic flux which passes through this coil. (0.008 Weber).

2) A wire of 10 cm length, carrying a current 5 A, is placed in a magnetic field of 1Tesla flux density. Calculate the force acting on the wire, when:

a) the wire is at right angles to the magnetic field. (0.5 N)

b) the angle between the wire and the field is 45°. (0.356 N)

c) the wire is parallel to the magnetic flux lines. (0)

3) A straight wire of diameter 2 mm carries a current of 5A. Find the magnetic flux density at a distance of 0.2 m from the wire. ($5x10^{-6}$ Tesla).

4) A circular loop of radius 0.1 m carries a current of 10 A. What is the magnetic flux density at its center? (the loop has one turn). (2π x 10^{-5} Tesla)

5) What is the magnetic flux density at a point on the axis of a solenoid of length 50 cm carrying a current of 2A and has 4000 turns? (0.02 Tesla).

6) A rectangular loop (12 x 10 cm) of 50 turns, carrying a current of 3 A, is placed in a magnetic field of 0.4 Tesla flux density, such that the plane of the loop is parallel to the field. Calculate the torque acting on the loop. (0.72 Nm)

7) A galvanometer's loop of 5 x 12 cm^2 and 600 turns is suspended in a magnetic field of 0.1 Tesla flux density. Calculate the current required to produce a torque of 1 Nm. (2.78 A).

8) A loop of cross-sectional area 0.2 m^2 and 500 turns,carrying a current of 10 A is placed at 30° between the normal to its plane and a magnetic field of 0.25 Tesla flux density. Calculate the torque acting on the loop.

(125 Nm).

9) The coil of an ammeter is capable of carrying current up to 40 mA. If the resistance of the coil is 0.5Ω, and it is desired to use the ammeter for measureing a current of 1 A, What is the resistance value of the required shunt? (0.021Ω)

10) A galvanometer gives full scale deflection at current 0.02 A, and its terminal voltage is 5 V. What is the value of the multiplier resistance required to make it valid to measure potential differences up to 150 V? (7250Ω)

11) A voltmeter reads up to 150 V at full scale deflection. If the resistance of its coil is 50Ω and the current flowing is 4 x 10^{-4} A. Calculate the resistance of the potential multiplier connected to the coil? (374950Ω)

12) A galvanometer reads up to 5A and has a resistance of 0.1 Ω. If we want to increase its reading 10 times, what is the value of the required shunt resistor? (0.0111Ω).

13) An ammeter has resistance 30Ω. Calculate the value of the required shunt resistor to

(Decrease the sensitivity) to one third, and determine also the total resistance of the ammeter and the shunt resistor. (15 Ω, 10Ω).

14) A galvanometer of resistance 54Ω, when connected to a shunt (a), the current flowing through the galvanometer is 0.1 of the total current. But if connected to a shunt (b), 0.12 of the total current flows through the galvanometer. Find the resistances of a and b. (6 Ω, 7.364Ω)

15) A moving coil galvanometer of resistance 50 ohms gives full scale deflection at current 0.5A. How could it be converted to measure:

a) potential differences up to 200V? (350 Ω in series).

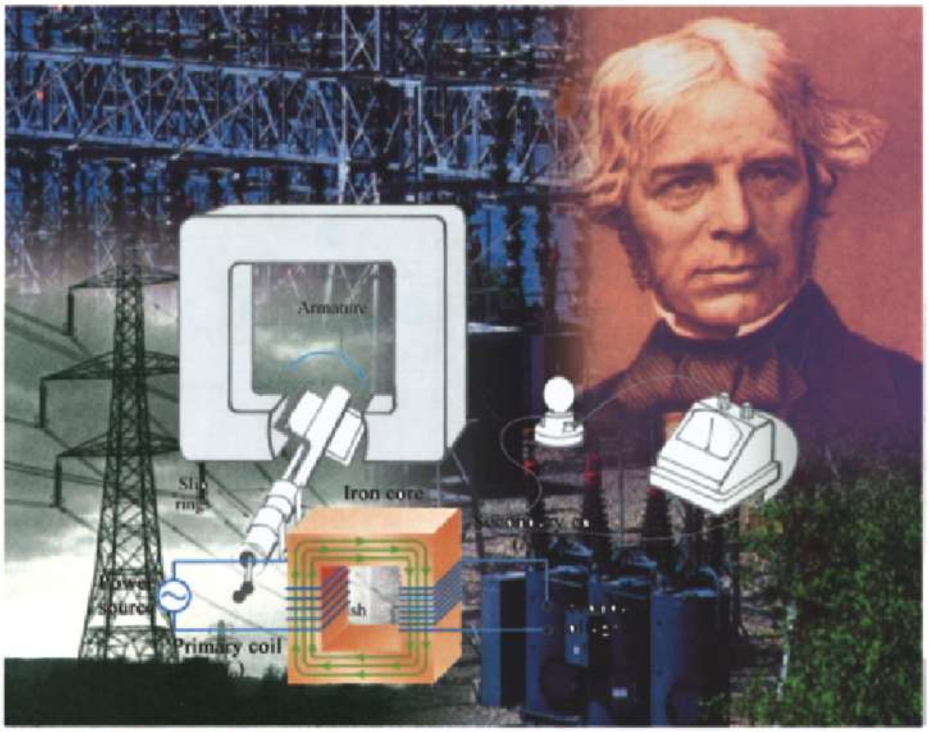
b) electric currents up to 2A? (16 2/3 Ω in parallel)

16) A milliammeter of resistance 5Ω has a coil capable of carrying a current of 15 mA. It is desired to use it as an ohmmeter using an electric cell of 1.5V having internal resistance 1Ω. Calculate the required standard resistor, and calculate the external resistance needed to make the pointer deflect to 10mA? Calculate the current that flows through it when connected to an external resistor of 400Ω ?

(94Ω, 50Ω, 3mA)

Dynamic Electricity & Electromagnetism

UNIT 1



Chapter 3: Electromagnetic Induction

Chapter 3 Electromagnetic Induction

Overview

It has been noticed that the passage of an electric current in a conductor produces a magnetic field. Soon after Oersted's discovery that magnetism could be produced by an electric current,a question arose, namely, could magnetic field produce an electric current ?

This problem was addressed by Faraday through a series of experiments which led to one of the breakthroughs in the field of physics, namely, the discovery of electromagnetic induction. On the basis of such a discovery, the principle of operation and function of most of the electric equipment - such as the electrical generators (dynamos) and transformers - depend.

Faraday's Experiment:

Faraday made a cylindrical coil of insulated copper wire, such that the coil turns were separated from each other. He connected the two terminals of the coil to a sensitive galvanometer having its zero reading at the mid point of its graduated scale, as shown in Fig (3-1) . When Faraday plunged a magnet into the coil, he noticed that the pointer of the galvanometer was deflected momentarily in a certain direction. On removing the magnet from

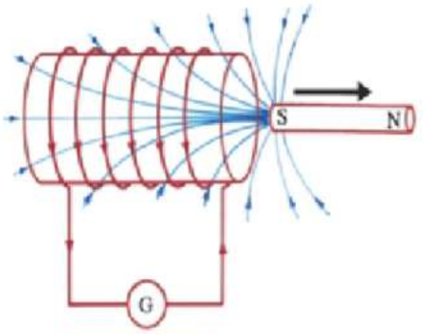


Fig (3 -1a)

The magnet is plunged into the coil

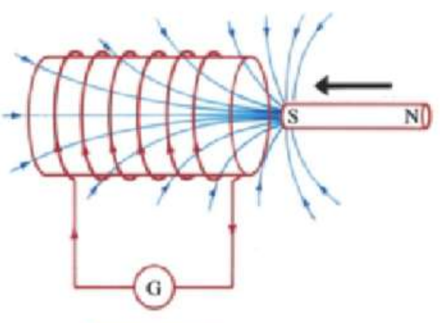


Fig (3 -1b)

The magnet is pulled out of the coil

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the coil, a deflection of the pointer was noticed in the opposite direction. This phenomenon is called "electromagnetic induction". According to this phenomenon, an electromotive force and an electric current are induced in the coil, when the magnet is plunged into or removed from the coil. As a result, Faraday concluded that the induced electromotive force and also the induced electric current were generatd in the circuit as a result of the time variation of the magnetic flux linked with the coil during the motion of the magnet.

Moreover, the action of the magnet is met by a reaction from the coil.If the magnet is plunged into the coil, the induced magnetic field acts in a way to oppose the motion of the magnet. If the magnet is pulled out, the induced magnetic field acts to retain (or keep) the magnet in. Faraday concluded that the induced emf and current were generated in the circuit as a result of the time variation of magnetic field lines as they cut the windings of the coil while the magnet was in motion.

Faraday's laws:

From the above Faraday's observations, one can conclude the following:

1) the relative motion between a conductor and a magnetic field in which there is time variation of the magnetic flux linked with the conductor, induces an electromotive force in the conductor. Its direction depends on the direction of motion of the conductor relative to the field.

2) the magnitude of the induced electromotive force is proportional to the rate by which the conductor cuts the lines of the magnetic flux linked with it, i.e., $emf \propto \frac{\Delta \phi_m}{\Delta t}$

where $\Delta\phi_m$ is the variation in the magnetic flux intercepted by the conductor through the time interval Δt

3) the magnitude of the induced electromotive force is proportional to the number of turns N of the coil which cut (or link with) the magnetic flux., i.e.,

$$emf \propto N$$

Thus, from the analysis of the above mentioned results, one can conclude the following relation:

$$emf = -N \frac{\Delta \phi_m}{\Delta t} \qquad (3-1)$$

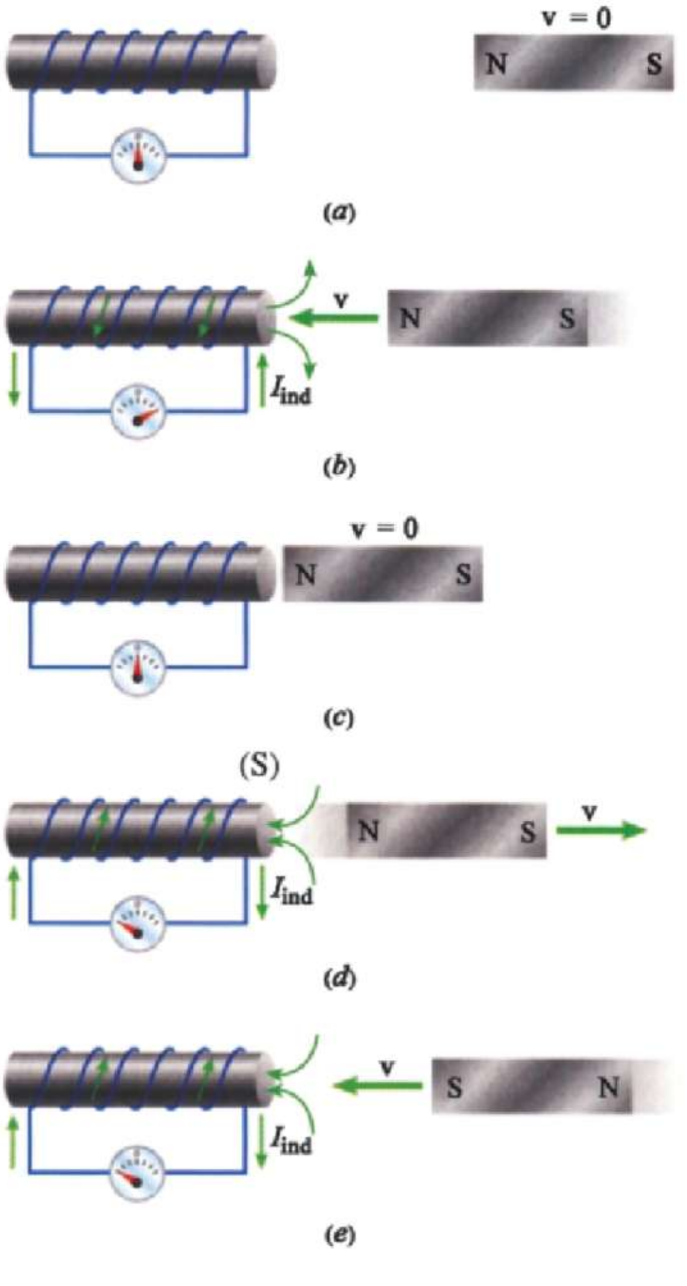


Fig (3 – 2)
Lenz's law

This is known as Farady's law of electormagnetic induction. The negative sign in the above relation indicates that the direction of the induced etectromotive force or the induced current tends to oppose the cause producing it. This rule is known as Lenz's rule.

Lenz's rule

The induced current must be in a direction such as to oppose the change producing it.

Fig (3 -2) illustrates a direct application of Lenz's rule :

The direction of the induced current in a straight wire:

In one of his several experiments, Faraday showed that the induced current in a straight wire flowed in a direction perpendicular to the magnetic field. Many years later. Fleming concluded a simple rule:

Fleming's right hand rule

Extend the thumb,pointer and the middle finger of the right hand, mutually perpendicular to each other. Let the pointer points to the direction of the field, and the thumb in the direction of motion, then the middle finger (with the rest of the fingers) will point to the direction of the induced current or voltage as shown in Fig (3 - 3).

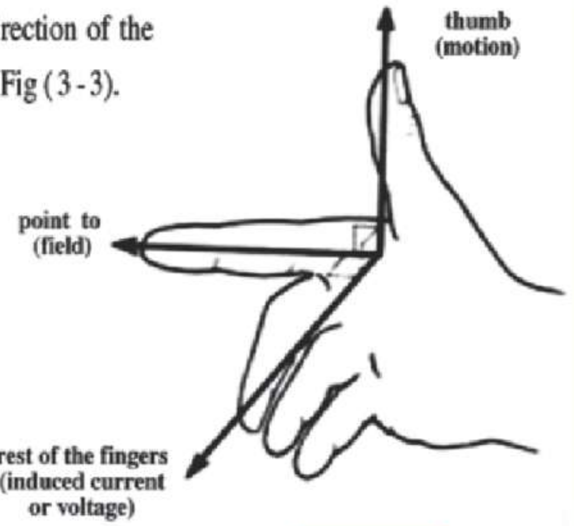


Fig (3 - 3)
Fleming's right hand rule

Mutual induction between two coils:

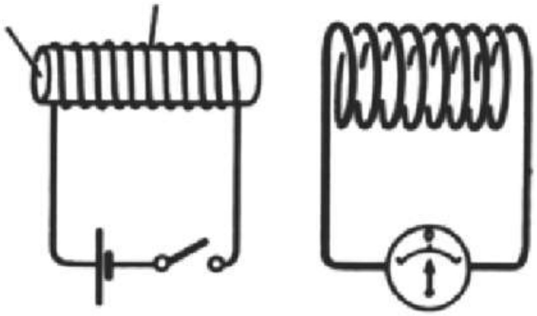


Fig (3 - 4A)

in case there is no current in the first coil, there is no emf in the second coil.

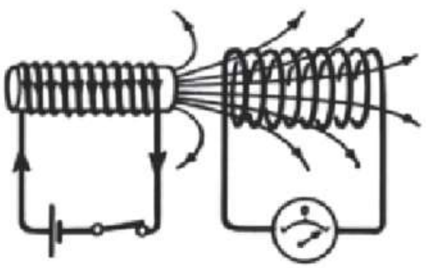


Fig (3 - 4b)

at the instant of closing the ciruit of the first coil, an emf is generated in the second coil.

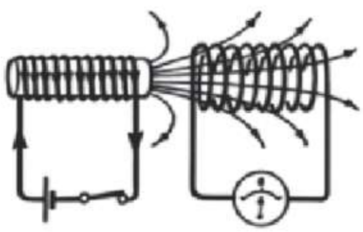


Fig (3 - 4c)

after the current in the primary is steady (the flux is steady) emf in the secondary coil: 0

If the two stationary coils are arranged such that one coil surrounds the other., i.e., one coil is plunged into the second one, or even one is placed in the neighborhood of the other as shown in Fig.(3 -4), then the variation in the intensity of the electric current in one of the two coils (opening and closing the switch) will induce an electromotive force in the other coil, according to Faraday's law. This induced electromotive force is proportional to the rate of change in the magnetic flux linked with the other coil. Since the magnetic flux is proportional to the intensity of current in the first coil.

$$(emf) \propto \frac{\Delta I_1}{\Delta t}$$

$$(emf) = -M \frac{\Delta I_1}{\Delta t} \qquad (3\text{-}2)$$

where M is the coefficient of mutual induction (mutual inductance) of the two coils. Its unit is VsA^{-1} and is equivalent to what is called "Henry". Thus, the henry is the unit used to measure the inductance in general. The negative sign in equation (3 -2) follows from Lenz's rule, namely, that the direction of the induced electromotive force (or the direction of the induced current) is such as to oppose the cause producing it. The coefficient of mutual inductanc between two coils depends on the following factors.

1. the presence of an iron core inside the coil.
2. the volume of the coil and the number of its turns.
3. the distance separating them.

The transformer is considered as a clear example of mutual induction

Experiment to study mutual induction

One can study experimentally the mutual induction as follows:

Connect one of the two coils in a circuit which contains a battery, a switch and a rheostat. One coil is called the "primary coil", while the other coil - connected to a sensitive galvanometer with its zero point at the middle of its scale - is known as the "secondary coil". Fig(3 -5). Let us do the experiment as follows:

1) Close the circuit of the primary coil, while plunging the primary coil into the secondary coil. One notices a deflection in the galvanometer in a certain direction, indicating the generation of an induced electromotive force in the secondary coil due to the variation of the number of magnetic flux lines linked with the turns of the secondary coil. On taking away the primary coil from the secondary coil, one notices that the pointer of the sensitive galvanometer is deflected in the opposite direction.

2) Plunge the whole primary coil to reside in the secondary one, then increase the intensity of the current in the primary coil. Notice the deflection of the pointer of the galvanometer in a certain direction. Decrease the current in the primary, and notice that the deflection of the pointer takes place in the opposite direction. This indicates the generation of an induced electromotive force in the secondary coil on increasing or decreasing the intensity of the current in the primary coil.

3) With the primary coil inside the secondary one, close the circuit of the primary coil, a deflection is noticed in the galvanometer in a certain direction. Open the primary circuit, and notice that the deflection is in the opposite direction. This indicates that an electromotive force is induced in the secondary coil upon switching on or switching off the primary circuit.

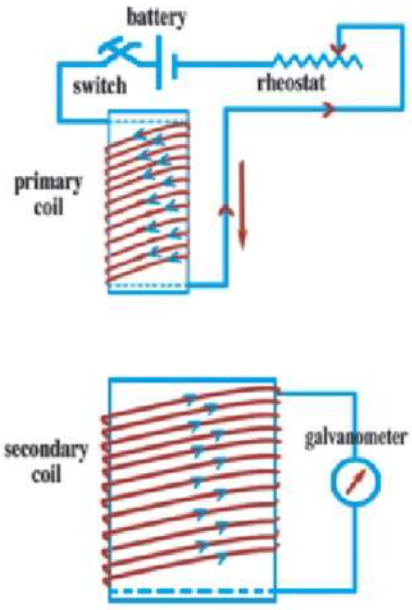


Fig (3 - 5)
Mutual inductance between two coils

The analysis of the above mentioned observations leads to the following conclusions:

I. The pointer of the sensitive galvanometer deflects in a certain direction in the following cases:

a) bringing the primary coil close to the secondary coil or when the primary coil is plunged inside the secondary one.

b) increasing the intensity of the current in the primary coil.

c) switching on the primary circuit.

In all cases above, there is a positive increase in magnetic flux linkage and the induced emf in the secondary coil increases as the affecting magntic field increases with time. The induced current is in opposing direction to that in the primary. In such a case, the induced

magnetic field will be in a direction as to resist the increase in the affecting magnetic field.

II. The pointer of the galvanometer deflects in the opposite direction in the following cases:

a) on the withdrawal of the primary, or taking it far away from the secondary coil.

b) on decreasing the intensity of the current in the primary.

c) on switching off the primary circuit.

In the above cases, he intensity of the magnetic field affecting the secondary coil decreases and the magnetic flux linkage decreases. The induced emf in the secondary coil decreases as the affecting field decreases with time. The direction of the induced electromotive force (and the induced current) is in the forward direction, so as to produce a magnetic field in the same direction as the current in the primary. This in turn resists the decrease in the affecting magnetic field. All these observations clarify Lenz's rule, where the direction of the induced current is such as to resist (or to oppose) the time variation causing it.

Self induction of a coil:

One can understand what is meant by self induction of a coil by connecting the coil of a strong electromagnet (a coil of large number of turns) in series with a 6V battery, and a switch as shown in Fig (3 -6). Current passes in the considered coil, due to which a strong magnetic field is formed, since each turn acts as a small magnet. The magnetic flux links with the neighboring turns.

On switching off the circuit, it is noticed that an electric spark is passed between the two terminals of the switch. This is explained as follows.

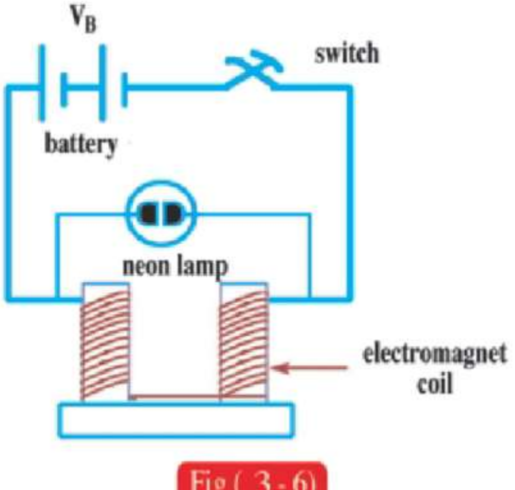


Fig (3 - 6)
Effect of self induction in a coil

When the coil circuit is switched off, the current ceases to pass in it, and this is associated with a decrease of the magnetic field of the neighboring turns to zero. This in turn is accompanied by a time variation of the flux linkage, i.e., each turn cuts the diminishing lines of the magnetic flux, and thus, an induced electromotive force is generated in the coil.

The induced electromotive force is formed in the turns of the coil as a whole as a result of the self induction of the coil itself. This induced electromotive force is generated due to the self induction of the coil on switching off or switching on the circuit following Lenz's rule. Thus, an induced electric current is generated in the same direction as the original current. When the circuit is switched off, to retain the existing current, a spark is formed between the two terminals of the switch. When the number of turns of the coil is large, the induced emf on switching off the circuit will be much larger than that of the battery, This causes a neon lamp connected in paralle1 between the two terminals of the switch to glow(a neon lamp requires a potential difference about 180V to glow).

Since the induced electromotive force is proportional to the rate of change of the current in the coil, then the emf induced by self induction is directly proportional to the rate of change of the current in the coil. That is :

$$(\text{emf}) \propto \frac{\Delta I}{\Delta t}$$

$$\therefore (\text{emf}) = -L \frac{\Delta I}{\Delta t} \qquad (3-3)$$

where L is a constant of proportionality known as the coefficiont of self induction (self inductance) of the coil, and the negative sign in equation (3 -3) indicates that the induced electromotivc force opposes the change causing it (Lenz's rule).

$$L = -\frac{\text{emf}}{\Delta I / \Delta t}$$

Thus, the self inductance of a coil is defined as:

It is the electromotive force induced in the coil when the current passing through it changes at a rate equals one Ampere per second. The self inductance is measured in the unit henry.

The Henry :

It is the self-inductance of a coil in which an emf of one volt is induced when the current passing through it changes at a rate of one Ampere per second $(vsA)^{-1}$.

The self inductance of a coil depends on:

a) its geometry.

b) its number of turns.

c) the spacing between the turns.

d) the magnetic permeability of its core.

Henry

Among the applications of self induction is the fluorescent lamp, where magnetic energy is stored in the coil. This energy is discharged in an evacuated tube filled by an inert gas, causing collisions of its atoms and their subsequent ionization and collision with the walls of the tube.

The inner walls are coated with a fluorescent material which causes visible light to be emitted upon the collision of the inert gas ions with it.

Eddy Currents:

If the magnetic flux changes with time through a solid conductor ,currents will be induced in closed paths in the conductor. Such currents are called "eddy currents". The change in the intercepted magnetic flux is effected either by moving the solid in a suitable magnetic field or by subjecting the metallic solid to an alternating magnetic field(for example field due to an AC current). The eddy currents are associated with heating effects. Thus, they are useful in melting metals in what is called the induction furnaces.

Induced emf in a moving straight wire:

We place a straight wire of length ℓ perpendicular to a uniform magnetic field of magnetic flux density B (perpendicular to the paper inwardly) (Fig11-7.) The wire is moved in a direction perpendicular to the field at velocity v, so that it is displaced a distance Δx in time Δt. The change in area is

$$\Delta A = \ell \Delta x$$

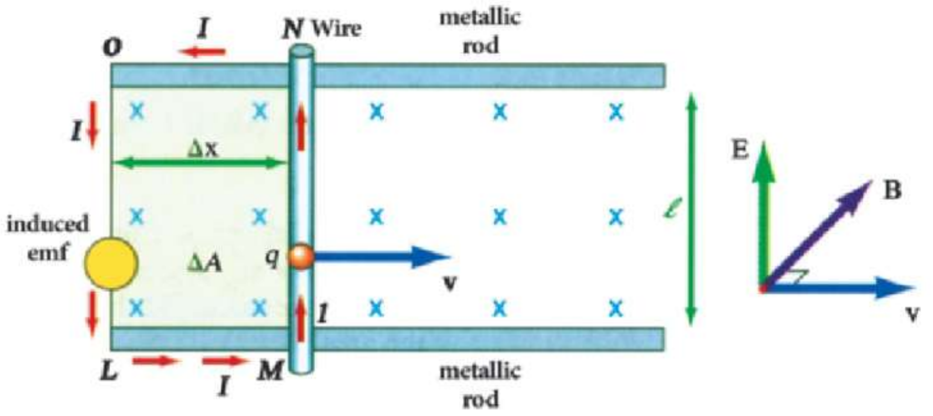


Fig (3-7)

Generation of an induced emf in a straight wire

The change in flux is

$$\Delta \phi_m = B \Delta A = B l \Delta x$$

The emf is determined from the relation

$$emf = -\frac{\Delta \phi_m}{\Delta t}$$

$$emf = -\frac{B l \Delta x}{\Delta t} = -B l v$$

The minus sign is required according to Lenz's rule. The emf is

$$\boxed{emf = Blv} \qquad (3\text{-}5)$$

If the angle between the direction of velocity and the direction of the magnetic flux is θ, then

$$\boxed{emf = Blv \sin\theta} \qquad (3\text{-}6)$$

Alternating current generator:

The AC generator (or the dynamo) is a device which converts the mechanical energy into electrical energy. In a generator, a coil rotates in a magnetic field, and the resulting induced current can be transferred (or transmitted) by wires for long distances.

The simple electric generator consists as shown in Fig (3 -8) of four main parts :

a) a field magnet.

b) an armature.

c)two slip rings.

d) two brushes.

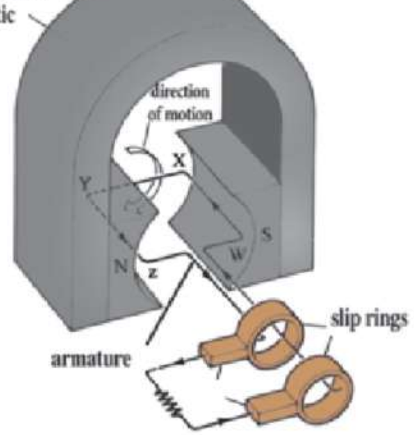


Fig (3 - 8)
A simplified schematic for an AC generator (dynamo)

The field magnet may be a permanent magnet or an electromagnet. The armature consists of a single loop of wire or coil of many turns suspended between the two poles of the field magnet. A pair of slip rings are connected, one to each end of the loop. They rotate with the loop in the magnetic field. The induced current in the coil passes to the external circuit through two graphite brushes, each touching one of the two corresponding slip rings. Fig (3-9) shows the direction of rotation of the armature between the poles and the direction of the induced current at a certain instant. The loop rotates around its axis in a circle of radius r. Its linear velocity is

$$v = \omega r$$

where ω is the angular velocity equal to $2\pi f$, (where f is the frequency). Substituting for

v in equation (3-6), we find :

$$emf = B \ell \omega r \sin \theta$$

where θ is the angle between the direction of velocity and the magnetic flux density, or the angle between the normal to the surface M and B. When the coil is perpendicular to the flux, the induced emf is zero. Thus, the induced emf is given by

$$emf = 2B \ell \omega r \sin \theta$$

But the area of the armature A is

$$A = (\ell)(2r)$$

$$emf = BA \omega \sin \theta$$

If the number of turns is N, the instantaneous induced emf is

$$emf = NBA\omega \sin \theta \qquad (3\text{-}7)$$

From this relation, the induced emf changes according to a sine curve (sinusoidally) with time (Fig 11-10). The induced emf changes from a positive maximum at $\theta = 90^\circ$, to zero at $\theta = 0$. The maximum induced emf (noting $\sin 90^\circ = 1$) is

$$(emf)_{max} = NBA\,\omega = NBA\,(2\pi f) \qquad (3\text{-}8)$$

We may express the instantaneous induced emf by

$$emf = (emf)_{max} \sin \theta \qquad (3\text{-}9)$$

Since $\theta = \omega t = 2\pi f t$. Thus:,

$$emf = (emf)_{max} \sin 2\pi f t \qquad (3\text{-}10)$$

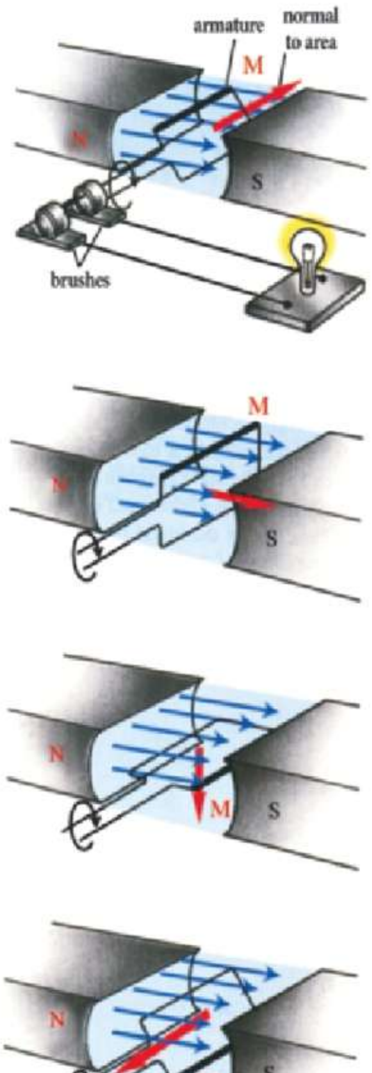


Fig (3-9)

Change of the direction of the induced current throughout one complete revolution of the armature

From Fig (3 -10), we see that the induced current changes direction every half a revolution. It follows a sine wave. From figure, we can also understand the meaning of f.

Throughout a complete revolution, the current increases from zero to a maximum, then decreases to zero, then reverses direction, and increases in the negative direction up to a negative maximum. Then, it heads back to zero. In one complete revolution, one complete oscillation has occurred. The number of oscillations per second is the frequency f. The frequecy of home use power is 50Hz

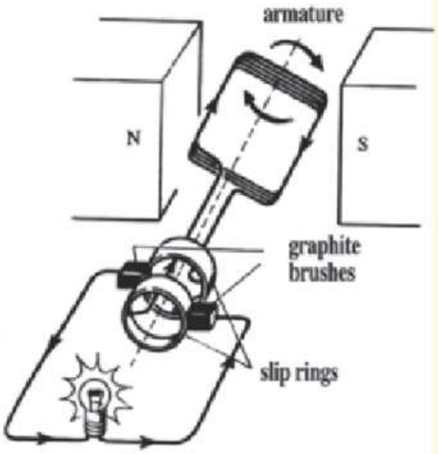


Fig (3 -10a)
AC generator

Example:

The coil of a simple AC generator consists of 100 turns, the cross sectional area of each is 0.21 m^2. The coil rotates with frequency 50 Hz (cycles/second) in a magnetic field of constant flux density $B = 10^{-3}$ Weber/m^2. What is the maximum induced emf generated? and what is the instantaneous value at $\theta = 30°$?

Solution:

$$(emf)_{max} = NBA\,\omega = NBA\,(2\pi f)$$

$$= 100 \times 10^{-3} \times 0.21 \times 2 \times \frac{22}{7} \times 50 = 6.6 \text{ V}$$

Thus, the maximum induced emf generated equals 0.6 volts.

$$emf = (emf)_{max} \sin\theta = 6.6 \times \sin 30° = 6.6 \times \frac{1}{2} = 3.3 \text{ V}$$

It is worth remembering that the induced current is directly proportional to the induced emf. Thus, the instantaneous value of the induced current is given by :

$$I = I_{max} \sin(2\pi f t)$$

This induced current reaches its maximum value when the induced emf reaches its maximum value, and it vanishes as the induced emf is zero.

Effective value of the alternating current:

It is worth mentioning that the average value of an AC current equals zero, because the AC current changes from (I_{max}) to ($-I_{max}$). Neverthless, the electric energy is consumed as thermal energy due to the motion of electric charges, and the rate of the electric energy consumed is proportional to the square of the intensity of the current.

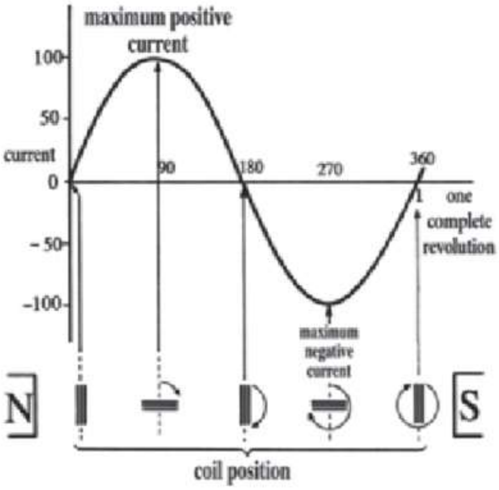


Fig (3-10b)
The relation between current and angle of rotation(sine wave)

The effective value of the intensity of the alternating current is the value of the direct current which generates the same rate of thermal effect in a resistance (or the same power) as that generated by the considered AC current.

$$I_{eff} = 0.707\, I_{max} \qquad (3\text{-}11)$$

The value I_{eff} is called the "effective value of the alternating current".

There is a similar relation for the effective electromotive force, that is :

$$(emf)_{eff} = 0.707\, (emf)_{max} \qquad (3\text{ - }12)$$

$$V_{eff} = 0.707\ V_{max}$$

Example:

If the effective intensity of current in a circuit equals 10 A, and the effective voltage is 240 volts,what is the maximum value for current and voltage ?

Solution:

$$I_{eff} = 0.707\, I_{max}$$

Also, $$I_{max} = \frac{10}{0.707} = 14.14\ A$$

$$V_{eff} = 0.707\, V_{max}$$

$$240 = 0.707\, V_{max}$$

$$V_{max} = \frac{240}{0.707} = 339.5\ V$$

Current rectification in the dynamo:

Many electrical processes, such as the production of some metals through the electrolysis of their compounds require unidirectional current or direct current. This in turn necessitates the conversion of the alternating current into direct current. This process is called rectification.Also, an AC generator may be converted to a DC generator. To fulfil this purpose, one has to replace the two metallic rings by what is called a "commutator". The

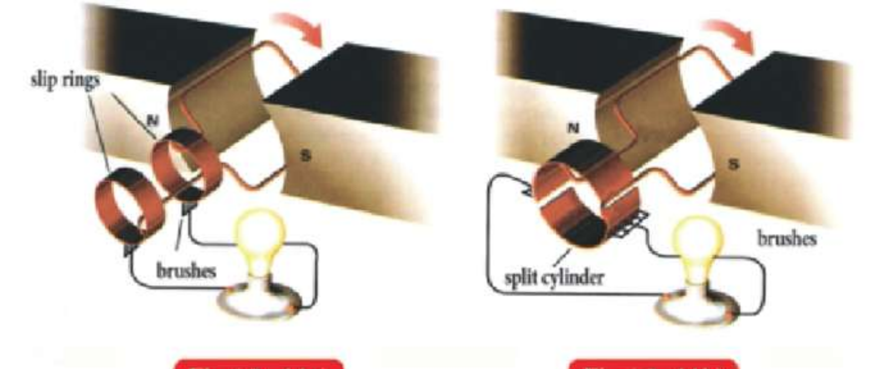


Fig (3 -11a) AC generator

Fig (3-11b) DC generator

commutator consists of two halves 1 and 2 of a hollow metallic cylinder split in between, and are well insultated from each other as shown in Fig (3-11).Two brushes F_1 and F_2 touch the two halves during the rotation of the coil. The external circuit is connected to the two brushes F_1 and F_2. It is necessary that the two brushes F_1 and F_2 touch the insulator between the two halves at the moment when the plane of the coil is perpendicular to the magnetic field, i.e, at the instant when the generated electromotive force in the coil is zero.

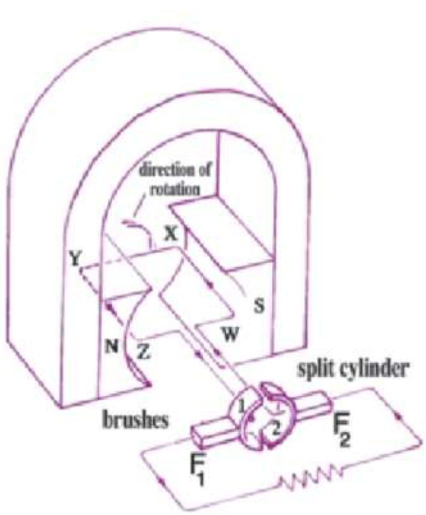


Fig (3-11b)
Use of a split cylinder rectifies the current

Let us consider that the coil starts rotation in the direction shown (Fig. 3-11c).During the first half rotation, brush F_1 touches the half cylinder (1), while brush F_2 touches the other half (2) of the cylinder. The current in such a case will pass in the coil in the direction w x y z. As a result, the current passes in the external circuit in the direction from F_1 to F_2 during the first half of the cycle. In the second half of the cycle, the electric current reverses its direction in the coil, i.e., the current passes in the coil in the direction z y x w. At the same time, brush F_1 will be in contact with the half(2), while F_2 will be in contact with the half(1), i.e., the two halves of the commutator reverse their position relative to the two brushes. In such a case, the current in the external circuit passes from, F_1 to F_2, which is the same direction as that in the first half of the cycle.

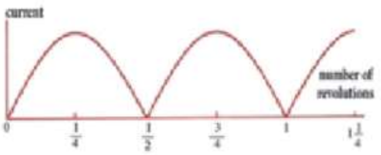


Fig (3-11d)
Unidirectional current versus θ (sine wave)

Continuing the rotation, the brush F_1 acts as a positive pole, while F_2 acts as the negative pole of the dynamo. Accordingly, the current in the external circuit will be always in one direction as shown. It is noticed that using the commutator renders the induced emf in Fig (3 -11d) in one direction, but its value changes from zero up to a maximum value, then decreases again to zero during each half cycle of the coil rotation, but it is always in one direction.

To obtain a uni-directional current of approximately constant value, i.e., to obtain a nearly DC (value), many coils separated by small angles are used. A cylinder is used which is split into a number of segments, double the number of coils. Thus, the current in the external circuit is almost constant. This is the way to obtain a DC generator (Fig 3 -12).

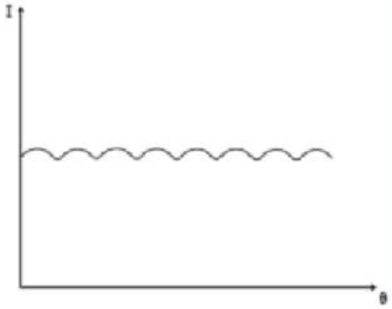


Fig (3 -12)
Nearly DC current

The transformer:

The electric transformer is a device whose function is based on the mutual induction between two coils, and is used to step up or to step down an AC voltage. Transformers are used to transfer the electric energy from generators at electric power stations. Such transformers are called step - up transformers, while the transformers used at the zones where the energy has to be distributed among buildings are called step-down transformers. The transformer as shown in Fig (3 -13) consists of two coils: a primary coil and a secondary coil. The two coils are wound around a soft iron core made of thin iron sheets

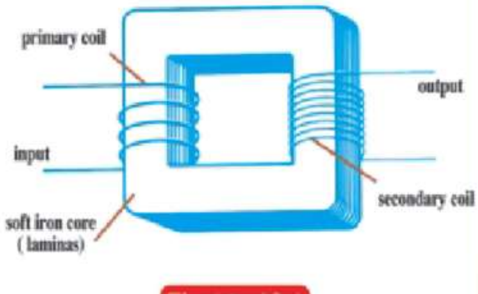


Fig (3 -13a)
Step UP transformer

(laminas) insulated from each other, to minimize the effect of eddy currents and to minimize the dissipated electric energy. When an electric current passes in the primary coil, a magnetic field is generated. The core makes the lines of such a field pass through the secondary coil.

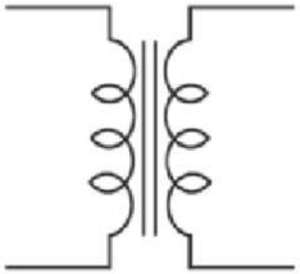


Fig (3 -13b)
Transformer symbol

The relation between the two emfs in the two coils of the transformer:

When the primary coil is connectcd to a source of AC voltage, the variation in the magnetic field linked with the primary current generates an induced emf in the secondary coil having the same frequency. The induced emf in the secondary is determined from the relation:

$$V_s = -N_s \frac{\Delta \phi_m}{\Delta t}$$

where, N_s is number of turns of the secondary coil and $\frac{\Delta \phi_m}{\Delta t}$ is the rate of change of the mangetic flux linked between the primary through the secondary coil. The electromotive force in the primary is in turn related to the rate of change of the magnetic flux and is determined from the relation :

$$V_p = -N_p \frac{\Delta \phi}{\Delta t}$$

where, N_p is the number of turns of the primary coil. Assume that the wasted magnetic energy is negligible, i.e., there is no considerable loss in the magnetic flux, i.e., the whole resulting magnetic flux passes through the secondary coil (no stray lines). Dividing the above two relations one can get the following formula :

$$\boxed{\frac{V_s}{V_p} = \frac{N_s}{N_p}} \qquad (3 - 13)$$

This equation shows the interrelation between the emf V_s in the secondary and V_p in the primary. If N_s is larger than N_p, one has a step-up transformer, where the emf in the secondary coil will be larger than the emf in the primary one. For example, if the number of turns of the secondary coil is twice that for the primary coil, one gets $V_s = 2V_P$.

While, for the case when N_s is less than N_p one gets a step-down transformer, where, in such a case V_s will be less than V_p.

The relation between the current intensities in the two coils of the transformer:

Let us assume that there is no loss in the electric energy in the transformer (almost zero resistance), then according to the law of conservation of energy, the electric energy made available by the source in the primary coil must equal that delivered to the load in the secondary coil.

$$V_p I_p t = V_s I_s t$$

From which the input power is equal to the output power, i.e,

$$V_p I_p = V_s I_s$$

Thus,

$$\therefore \frac{V_s}{V_p} = \frac{I_p}{I_s} \qquad (3 - 14)$$

From the equations (3 -13) and (3 -14),

$$\frac{I_s}{I_p} = \frac{N_p}{N_s} \qquad (3 - 15)$$

This shows that the intensity of the electric current in either of the two coils is inversely proportional to the number of its turns.

For example: if the number of turns of the secondary coil is twice that of the primary coil, then the intensity of current in the secondary coil equals half that in the primary coil.

From this argument, we see the importance of the use of the step-up transformer at the

electric generating power station (power plant), where it is desired to raise the voltage to a very high value. This is associated with small values of currents,consequently, losses decrease in the electric energy during power transmission along great distances. This is because the loss in power equals I^2R, where I is the intensity of the electric current passing through the wire, and R is the ohmic resistance of the wires . Therefore, if we succeed to decrease the intensity of the electric current passing through the transmission lines, by $\frac{1}{100}$, for example of its value in the primary coil through the use of a step-up transformer, the loss in energy is decreased by $\frac{1}{10000}$ of its value. At zones of energy distribution, one has to use step-down transformers, where the potential difference or voltage across the two terminals of the secondary coil is 220 Volt.This value represents the working household voltage for the electric lamps and most of the electric appliances used in our houses.

The uses of the electric transformer:

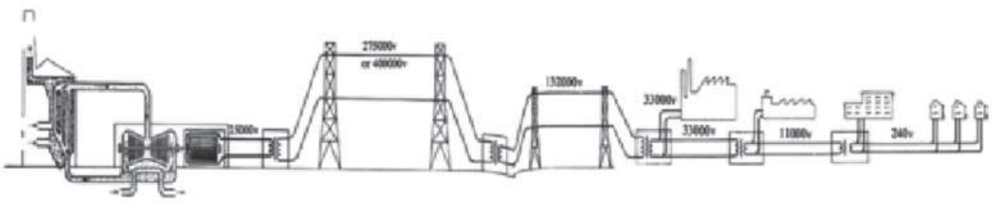


Fig (3-14)

Use of transformers in electric power transmission

Fig (3-15)

Transformers are used to transfer electric energy from the generating power stations to zones of distribution across very long distances through metallic wires with no considerable loss in energy. Step-up transformers are used at the stations while step-down transformes are used at the distribution regions (Fig 3-14, 3-15). Transformers, are also used in some domestic appliances, such as electric bells and refrigerators.

Efficiency of the transformer:

If there is no loss in electric energy in the transformer, i.e., the electric energy generated in the secondary coil equals the electric energy available in the primary coil, the efficiency of the transformer is said to be 100% efficient. Such a transformer is not available in every day life, because loss in energy must take place for the following reasons :

1) part of the electric energy is converted into thermal energy in the wires. To reduce such a loss, it is recommended to use metallic wires of least ohmic resistance.
2) part of the electric energy is converted in the iron core into thermal energy due to eddy currents. To minimize such a loss, the core is made of thin insulated sheets of siliconic soft iron having high specific resistivity and which decreases the eddy currents.
3) part of the energy is converted into mechanical energy consumed in the vibration of the molecules of the core. To minimize this effect, soft iron is used for the easiness with which its magnetic molecules move.

In general, if the lost energy represents 10% of the total original energy, the efficiency of the transformer is 90%. The efficiency of the transformer is defined as the ratio between the energy gained from the secondary coil to the energy given from the source to the primary coil within the same time, i.e.,

$$\eta = \frac{V_s I_s}{V_p I_p} \times 100 \qquad (3\text{-}16)$$

Learn at Leisure

Electromagnetic induction: magnetic recording

Electromagnetic induction is used in the recorder where an electrical signal (audio) is converted to magnetic field, which imagnetizis the magnetic tape through the recording head. During playback, the playhead reads what has been recorded, and converts it back to

an audio signal (Fig 3 -16). The same thing happens in the hard disk in the computer, where data is stored by magnetization. In this way, the data is not lost from the hard disk when the power of the computer is switched off.

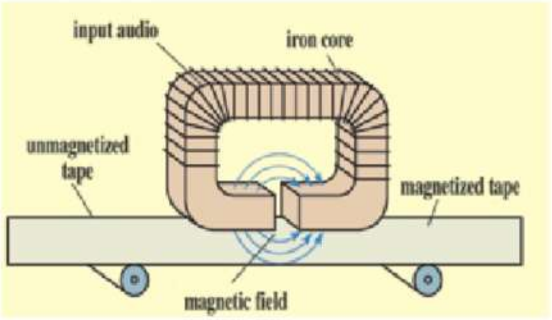


Fig (3 -16)

Use of electromagnetic induction in recording

Examples:

1- A trandformer connected to a 240 V AC power source gives 900 V output emf with current intensity 4A. What is the intensity of the source current assuming that the efficiency of the transformer is 100%?

Solution:

$$\because \frac{V_s}{V_p} = \frac{I_p}{I_s}$$

$$\therefore \frac{900}{240} = \frac{I_p}{4}$$

$$\therefore I_p = \frac{900 \times 4}{240} = 15 \text{ A}$$

2) An electric bell is connected to a transformer of efficiency 80% which gives 8 V output, while the input household voltage is 220 volts. What is the number of turns of the secondary coil if the number of turns of the primary coil is 1100 ? and what is the intensity of current in the secondary coil if the current in the primary coil is 0.1 A ?

Solution:

$$\eta=\frac{V_s\ I_s}{V_p\ I_p}x100$$

$$\eta=\frac{V_s}{V_p}x\frac{N_p}{N_s}x100$$

$$80=\frac{8}{220}x\frac{1100}{N_s}\ x100$$

$$N_s=50\ \text{turns}$$

$$\frac{I_s}{I_p}=\frac{N_p}{N_s}$$

$$\frac{I_s}{0.1}=\frac{1100}{50}$$

$$I_s=2.2\ A$$

Learn at Leisure

AC/DC

There are two types of current or voltage AC and DC .In the case of DC, Ohm's law dictates that what determines the current is the resistance.

In the case of AC, what determines the current are three elements,the resistor, the inductor and the capacitor. Household appliances use 220 V AC of frequency 50 HZ. Often, we need to convert this to a lower DC voltage, as in the case of the mobile charger and some other appliances.To do this, we use a down transformer and a rectifier.

DC motor:

It is a device which converts electric energy to mechanical energy. It operates on a DC source (battery) (Fig 3 -17). It consists in its simplest form of a rectangular coil abcd comprising a large number of turns of insulated copper wire wound around a soft iron core made of thin insulated sheets to cut down on eddy currents.

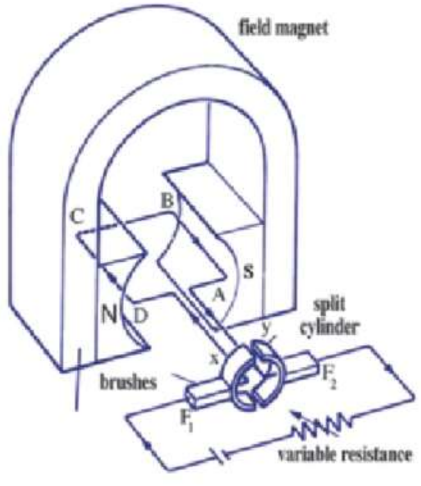


Fig (3 - 17)
DC motor

The core and the coil can rotate between the two poles of a strong horseshoe (U-shaped) field magnet. The two terminals of the coil are connected to two halves of a split cylinder (commutator). The two halves (x,y) are insulated from each other and capable of rotating around the axis of the coil.

The plane separating the two halves is perpendicular to the plane of the coil and the line connecting the two brushes is parallel to the lines of magnetic flux.

To operate the motor, the two brushes must be connected to the battery.

The motor and the galvanometer:

The principle of operation of the electric motor and that of the moving coil galvanometer are alike. The main difference is that the electric motor must rotate continuously in the same direction. The design of the electric motor necessitates that the two halves x,y of the cylinder must interchange positions relative to the two brushes F_1 and F_2 each half cycle. As a result, the electric current passing in the motor must reverse direction in the coil each half revolution.

Operation of a DC motor through one complete revolution:

Starting from a position at which the plane of the coil is parallel to the lines of the magnetic flux, and the brush F_1 - connected to the positive terminal of the battery - touches the half cylinder x, while F_2 - connected to the negative terminal of the battery - touches the half cylinder y as shown in Fig (3 -17). Thus, current passes in the coil in the direction dcba. Applying Fleming's left hand rule, one concludes that the wire ab is affected by a force in the upward direction, while the wire cd is affected by a force in the downward direction. The two produced forces (couple) form a torque, and the coil begins to rotate in the direction shown in the figure. As the coil rotates, the moment of the couple decreases gradually till it vanishes, when the coil plane becomes perpendicular to the lines of the magnetic flux. But the coil having gained a momentum will continue motion due to its inertia, which in turn pushes the coil to the other side. The two halves x and y of the commutator interchange position, such that the half cylinder x will be in touch with the brush F_2,while the brush F_1 will touch to other half cylinder y. Thus, the current in the coil will reverse direction and pass in the direction abcd. Applying "Fleming's left hand rule" for the new position of the coil shows that the force acting on the wire ab will be downward, while the force acting on the wire cd will be upwards. The obtained torque enables the coil to continue rotation in the same circular direction. The torque increases gradually to its maximum value when the plane of the coil becomes parallel to the lines of the magnetic flux. Then, it decreases to zero when the plane of the coil is perpendicular to the lines of magnetic flux. The inertia of the coil then causes it to continue rotating to the other side. This permits the two halves to interchange positions and with respect to the two brushes F_1 and F_2, and thus, the current in the coil is reversed once more. The coil continues rotating in the same circular direction making one complete revolution, and so on.

In order to increase the power of the motor, a number of coils may be used with equal

angles between their planes. The two terminals, of each coil are connected to two opposite splits of a cylinder. The cylinder is split into a number of segments twice that of the number of the coils. During rotation, each two opposite segments touch the two brushes F_1 and F_2 when their corresponding coil is in position of largest torque.

In a Nutshell

Definitions and Basic Concepts:-

Electromagnetic induction : It is a phenomenon in which an induced electromotive force and also an induced current are generated in the coil on plunging a magnet into orwithdrawing a magnet out of a coil.

- The presence of a soft iron core inside a coil concentrates the lines of magnetic flux that link with the coil. This in turn increases the induced electromotive force and also the induced current.
- **Faraday's law for the induced emf : The induced emf generated in a coil by electromagnetic induction is proportional to the time rate by which the conductor cuts the lines of magnetic flux and is also proportional to the number of turns of the coil.**
- **Lenz's rule: the direction of the induced current generated by induction is such that to oppose the change in the magnetic flux producing it.**
- **Fleming's right hand rule: Place the thumb, the pointer and the middle finger(with the rest of the fingers) of the right hand mutually at right angles. If the pointer points in the direction of the magnetic field and the thumb in the direction of motion then the middle finger (with the rest of the fingers) will point in the direction of the induced current.**
- **Mutual induction:** It is the electromagnetic interaction between two coils kept close to each other (or one inside the other).An electric current with time varying intensity passing in one coil (primary coil)will produce in the second one (secondary coil) an induced current in a direction such that to oppose the variations of the current intensity in the primary coil.

- **Self-induction:** It is the electromagnetic effect induced in the same coil when the intensity of the current increases or decreases.This effect acts to resist such a change in the intensity of current.
- **Coefficient of self-induction :** It is measured numerically by the electromotive force generated by induction in the coil when the intensity of the current passing through it changes at a rate of 1A/s.
- **The unit of measuring the self induction (Henry):** It is the self induction of a coil in which an emf of 1V is induced when a current passes through it which changes at a rate of 1A/s.

$$H = \frac{V.S}{A}$$

- The self-induction of a coil depends on :

a) its geometry.
b) its number of turns.
c) the spacing between its turns.
d) the magnetic permeability of its core.

- **The Dynamo (AC Generator):** It is a device used to convert the mechanical energy to electric energy(AC current and voltage) when its coil rotates in a magnetic field.

The simple dynamo (AC generator) consists of :

a) field magnet (strong magnet).
b) a coil of insulated copper wire suspended between the two poles of the magnet.
c) two metallic rings in contact with two graphite brushes connected to an external circuit.

- **A commutator:** (cylinder split into a number of insulated segments) is used to obtain a DC current and voltage (DC generator).
- **The alternating current:** It is current which changes periodically its intensity and direction with time according to a sinusoidal curve.
- **The electric transformer:** It is an electric device used to step up or step down an emf through mutual electromagnetic induction.

• **The efficiency of the transformer:** It is the ratio between the output electric energy given in the secondary and that available to the primary.

• **The electric motor:** It is an electric device used to convert the electric energy into mechanical energy .

Basic laws:

• The induced emf genrated in a coil of N turns as a result of time variation of magnetic flux$\Delta\phi_m$ linked with the coil in an interval of time is given by the relation:

$$emf = -N\frac{\Delta\phi}{\Delta t}$$

The nagative sign indicates that the direction of the induced emf (and thus the current) is such as to oppose the cause producig it.

• The emf induced in a secondary coil due to the time variation in the lines of magnetic flux resulting from a primary coil linking with the secondary coil in a time interval Δt is given by the relation :

$$emf = -M\frac{\Delta I}{\Delta t}$$

where M is the coefficient of mutual induction.

• The emf induced by self induction as a result of the current ΔI passing through the coil in a time Δt is given by the relation :

where L is the coefficient of self induction of coil.

$$emf = -L\frac{\Delta I}{\Delta t}$$

- The emf induced in a straight wire of lengh $\Delta \ell$ moving with a uniform velovity Δv making an angle θ with a magnetic field of magnetic flux B is given by the relation:

$$emf = B\ell v \sin\theta$$

- The emf induced in the dynamo is given by the relation :

$$emf = NBA\,\omega \sin\theta$$

where N is the number of turns, B is the magnetic flux density, A is the area of the face of the coil, θ is the angle confined between v and B, and ω is the angular velocity given by the relation :

$$2\pi \times \frac{\text{Number of revolution}}{\text{time in seconds}}$$

- The emf is maximum when $\theta^\circ = 90^\circ$ $(\sin 90^\circ = 1)$
  and minimum when θ = zero. $(\sin 0 = 0)$

- The relation between the effective value of the current I_{eff} and its maximum value I_{max} is given by :

$$I_{eff} = 0.707\, I_{max}$$

- The relation between the two electromotive forces in the two coils of the transformer:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

- The relation between the two currents in the two coils of the transformer is :

$$\frac{I_s}{I_P} = \frac{N_P}{N_s} \qquad \text{or} \qquad \text{ie. } \frac{V_s}{V_P} = \frac{I_P}{I_s} = \frac{N_s}{N_P}$$

- The efficiency of the transformer η is given by the relation :

$$\eta = \frac{V_s I_s}{V_p I_p} \times 100$$

Questions & Drills

I) Put (√) against the right answer:

1) The pointer of a galvanometer whose terminals are connected to a solenoidal coil will be deflected if one withdraws the magnet quickly from the coil because:

a) the number of the coil turns is very large.

b) the coil intercepts the lines of the magnetic flux.

c) the number of the turns of the coil is small.

e) the number of turns of the coil is suitable.

2) The needle of the galvanometer whose terminals are connected to a solenoidal coil deflects on the withdrawal of the magnet in a direction opposite to that which occurs on plunging the magnet into the coil because:

a) an induced current is generated in a direction opposite to that on plunging the magnet.

b) an electric current is generated.

c) the number of the lines of magnetic flux decreases.

d) the number of the lines of the magnetic flux changes.

e) the number of flux lines remains constant.

3) The emf induced in a coil on plunging a magnet into or withdrawing it out of a coil differs according to the difference in :

a) [the intensity of the current - the length of the wire - the number of the lines of flux].

b) [magnet strength - the velocity with which the magnet moves- the number of turns of the coil].

c) [the cross sectional area of the coil - the mass of unit length - the material from which the wire is made].

d) [the length of the wire - the number of turns - the type of the magnet].

e) [the magnetic flux density - time - the intensity of the current].

4) A current passes in the primary coil, then this coil is plunged into a secondary coil whose terminals are connected to a galvanometer. The deflection of its needle will be in a direction:

a) opposite to the current in the primary coil.

b) points to zero reading

c) increasing.

d) same as the current in the primary coil

e) variable

5) Opening the primary circuit while the primary coil is inside the secondary one, leads to the generation of :

a) an induced forward current.

b) an electric field

c) an induced back current.

d) an AC current.

e) a magnetic field.

6) The slow rate of growth of the current in the solenoidal coil is due to the:

a) production of forward current.

b) production of a magnetic field.

c) production of a back induced current opposing (resisting) the original one.

d) production of a magnetic flux.

e) production of an electric field.

7) The ohmic resistors are made of double wound wires:

a) to decrease the resistance of the wire.

b) to increase the resistance of the wire.

c) to avoid self-induction.

d) to eliminate the resistance of the wire.

e) to facilitate the connection process.

8) The direction of the current produced in the dynamo coil can be determined using:

a) Fleming's left hand rule.

b) Lenz's rule.

c) Fleming's right hand rule.

9) The rate with which the coil intercepts the lines of magnetic field in the dynamo is maximum when:

a) the plane of the coil is perpendicular to the flux lines.

b) the plane of the coil is inclined to the lines by an angle 30°

c) the face area of the coil is minimum.

d) the face area of the coil is maximum.

e) the plane of the coil is parallel to the lines of the magnetic flux.

10) The intensity of the current in the two coils of the transformer is :

a) directly proportional to the number of the turns.

b) inversely proportional to the number of the turns.

c) depending on the temperature of the wire.

d) depending on the substance of the wire.

e) depending on the temperature of the air (ambient temperature).

11) The power of an electric motor to rotate increases on using:

a) larger number of turns.

b) several coils with angles between their planes.

c) several magnets

d) an insulated copper wire.

e) a current rectifier.

12) The ratio between the electric energy in the secondary to that in the primary is called:

a) the lost energy.

b) the given energy.

c) the efficiency of the transformer.

d) the working strength of the transformer.

e) the gained energy.

II) Define the following :

1- Electromagnetic induction.

2- Faraday's law of induction

3- Lenz's rule.

4- Fleming 's right hand rule.

5- Mutual induction.

6- Unit of measuring the mutual inductance.

7- Self induction.

8- Coefficient of self induction.

9- The Henry.

10- The induction coil.

11- The AC current.

12- The dynamo.

13- The electric motor.

14 - The transformer.

15- The efficiency of the transformer.

16- The back emf in the motor.

III) Essay questions:

1) What are the factors on which the emf induced in a conductor depends ? Mention the relation between the emf. and such factors.
2) State Faraday's law of the emf induced in a coil, then show how to verify this practically?
3) What is meant by mutual induction between two coils? and what is meant by the coefficient of mutual induction? How - using the mutual induction - one can verify Lenz's rule?
4) If a current passes through a coil, deduce an equation relating the induced emf in the coil and the rate of change of the current in the coil. From this, deduce a definition for the coefficent of self induction and the Henry.
5) When does the emf induced in a coil become maximum ? and when does it become zero?
6) Explain an experiment to show the conversion of the mechanical energy into electrical energy, and another experiment to show the opposite conversion. Then, state the rule used to define the direction of the current in the first case and the direction of motion in the second case.
7) Deduce the relation by which one can evaluate the instantaneous emf induced in an AC generator.
8) What are the modifications introduced to the AC generator to render it a unidrectional generator ?
9) Describe the structure of the electric transformer ? then explain the principle of its opertion. What is meant by saying that the efficiency of the transformer is 80%?.
10) What is meant by the efficiency of the transformer? What are the factors which lower such an efficiency and how to deal with them?
11) Draw a labelled diagram showing the structure of the motor and explain its operation.

IV) Give reasons

1) The core of an electic transformer is made of thin sheets insulated from each other.
2) A bar of soft iron will not be magnetized if a double wound wire carrying a current is wound around it.
3) A wire free to move in a magnetic field moves when a current passes through it.
4) The transformer is not suitable to convert DC voltage.
5) The electric motor rotates with uniform velocity.
6) The induced current dies out in a straight wire faster than in a coil with air core, and in a coil with air core faster than in a coil wound around an iron core.
7) The metallic cylinder used to obtain a unidirectional current in the dynamo is split into two halves completely insulated from each other.

V) Drills

1) A coil of 80 turns, and cross sectional area 0.2 m^2 is suspended in a perpendicular position to a uniform magnetic field. The average induced emf is 2 V when it rotates 1/4 revolution through 0.5 s. Find the magnetic flux density.

(0.0625T)

2- If the magnetic flux density between the two poles of the magnet of a dynamo is 0.7 Tesla, and the length of its coil is 0.4 m, find the velocity of motion in such a field to obtain an induced emf in the wire equal to 1V. (3.57m/s)

3) A coil of a dynamo consists of 800 turns each of face area 0.25 m^2. It rotates at a rate of 600 revolutions per minute, in a field of magnetic flux density 0.3 Tesla. Calculate the induced emf when the angle made between the normal to the coil and the magnetic flux is 30°. (1885v)

4) A rod of copper of length 30 cm moves with at velocity 0.5 m/s in a perpendicular direction to a magnetic field of density 0.8 Tesla. Calculate the emf induced in such a rod. (0.12v)

5) An antenna of length one meter fixed in a motor car, which moves at velocity 80km/hour in a direction perpendicular to the horizontal component of the Earth's magnetic field. An emf of 4×10^{-4} V is induced in the antenna. In such a case, calculate the magnetic flux density of the considerd horizontal field.

(18×10^{-6}T)

6) Calculate the coefficient of self-induction for a coil in which an emf of 10 V is induced if the passing current changes at a rate of 40 A/s

(0.25 Henry)

7) The mutual induction between two faces of opposite coils is 0.1 Henry and the intensity of current in one of them is 4 A. If this intensity drops to zero in 0.01s, find the emf induced in the other coil.

(40V)

8) A rectangular coil of dimensions 0.4m x 0.2m and of 100 turns rotates with a uniform velocity 500 revolutions per minute in a uniform field of magnetic flux density 0.1 Tesla. The axis of rotation in the plane of the coil is perpendicular to the field. Calculate the emf induced in the coil.

(41.89 V.)

9) A step-down transformer of efficiency 90% has a primary coil voltage of 200 V and that of the secondary is 9 V. If the intensity of the electric current in the primary is 0.5 A, and the number of turns of the secondary is 90 turns, what is the intensity of the current of the secondary coil, and what is the number of turns of the primary?

(10 A, 1800 turns)

10) A step-down transformer connected to an AC power source of 2500 V gives a current of 80 A.The ratio between the number of turns of the primary and the secondary coils is 20:1 Assuming that its efficiency is 80%, find the emf induced across the two terminals of the secondary, and find also the current in the primary coil.

(100V,4A)

Chapter 4 Alternating Current Circuits

In the previous chapter you have studied the dynamo that generates the alternating current.

Worthy to remind you that the AC current changes its intensity periodically; increases from zero to a maximum value then drops to zero through a half cycle. Next to that, the current direction is reversed and its intensity goes from zero to maximum and drops back to zero through the other half cycle. This variation in current is typically repeated each cycle.

The alternating current is represented graphically by a sine waveform as shown in *figure (4-1)* since the current and the electromotive force vary their values and direction repeatedly according to a sinusoidal function of angles ranging from zero to 360°.

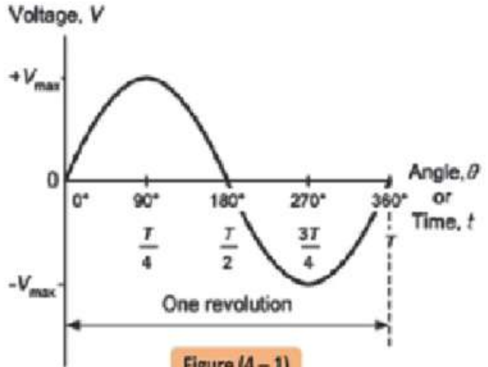


Figure (4 – 1)
Sinusoidal waveform of AC voltage or current

Frequency of AC current: is the number of complete cycles made by the AC current in one second. It is exactly the same as the number of complete revolutions made by the dynamo coil in one second.

The frequency of AC current used in Egypt is 50 Hz.

Advantages of AC current:

1- Its voltage can be stepped up or down as needed using electric transformers.
2- As alternating current, electrical power can be transmitted efficiently through power lines over long distances from the power plant to the consumer, minimizing power loss using **transformers.**
3- The AC current can be used for some processes but it would not be an appropriate choice in others such as electrolysis and electroplating.
4- The AC current can be rectified (converted) into DC current.
5- Both AC current and DC current have thermal effect when flowing through a resistor since heating effect is independent on the current direction.

Measuring the alternating current

Hot wire Ammeter:

Moving coil ammeters are not valid to measure the value of alternating current since it changes its intensity and direction constantly. The operation of moving coil meters requires a constant magnetic field affecting the coil in one direction. Because of this, the thermal effect of the alternating current is used instead, to measure its effective value. The instrument used is known as hot wire ammeter.

Construction and Operation:

A thin wire (H) is stretched tightly between two fixed ends A and B as shown in figure (4 - 2). The wire is made of platinum-iridium alloy that expands markedly when heated by the electric current Passing through it.

A silk thread (r) is permanently connected at the middle of the thin wire AB and wound once around a pulley (P) that can rotate about its axis. The thread is anchored at the other end (S) to a spring fixed at its other end. A pointer mounted to the pulley moves along a non-uniform scale. A small resistance R is connected in parallel to the wire AB as a shunt.

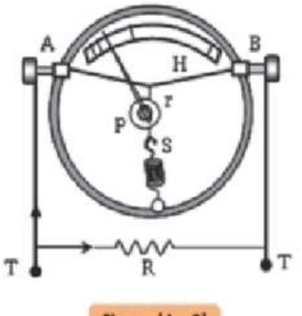


Figure (4 – 2)
Hot wire Ammeter

Operation of Hot wire Ammeter:

The ammeter is connected in series to the circuit. When the current to be measured is passed through the instrument, the wire AB is heated and expands. Consequently, the tension in the wire decreases (loosen). The silk wire pulls the hot wire due to the tension in the spring on the other side. The pulley rotates a little and the pointer deflects along the scale. The pointer stands at a definite reading when the temperature of the platinum-iridium wire becomes constant and the wire stops expanding. That is achieved when the rate of heat radiated from the wire becomes equal to the rate of heat generated in the wire. The pointer reading indicates the effective value of the AC current.

Hot wire ammeter is calibrated by connecting it with a moving coil ammeter in series in a direct current circuit. It is important to notice that the scale of hot wire ammeter is not uniformly divided. The scale divisions for equal increments of current increases as the value of current increases since the heat generated in a wire is directly proportional to the square of current value passing through it. ($Q \propto I^2$)

Disadvantages of hot wire ammeter:

1- Slow pointer deflection on passing the current and slow revert to zero when the ammeter is disconnected from the circuit.

2- The platinum-iridium wire is affected by changes in atmospheric temperature that may lead to a zero-error in measurement. However, it is requisite to make provision for this effect. This is done by mounting the working wire on a plate made of a metal having the same expansivity as that of the working wire itself.

Alternating Current (AC) Circuits

1) AC current and AC voltage in a non-inductive ohmic resistance:

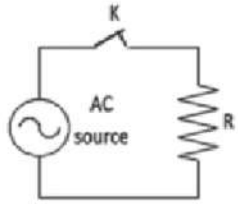


Figure (4 – 3)

AC circuit having a resistor

The figure (4 – 3) illustrates a series circuit containing an AC power supply, a switch and a non-inductive ohmic resistor.

On closing the circuit, the instantaneous voltage across the resistor is given by the relation:

$$V = V_{max} \sin \omega t \ldots\ldots (1)$$

Where V is the instantaneous voltage, V_{max} is the maximum voltage and ωt is the phase angle.

The instantaneous value of current is determined by the relation:

$$I = \frac{V}{R}$$

$$I = \frac{V_{max}}{R} \sin \omega t$$

$$I = I_{max} \sin \omega t \ldots\ldots (2)$$

Comparing equations (1) and (2), we find that both **V** and **I** in a non-inductive ohmic resistance have the same phase angle. This means that the current and voltage are synchronized and grow till they reach their maximum values simultaneously. In other words, voltage and current are in phase.

They can be represented graphically as in figure (4 – 4 a), or represented as two vectors having the same direction as in figure (4 – 4 b).

Figure (a)

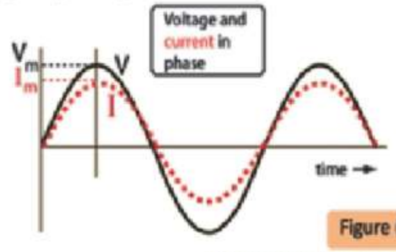


Figure (b)

Figure (4 – 4)

AC voltage and current have the same phase

2) AC current and AC voltage in an inductive coil of zero resistance:

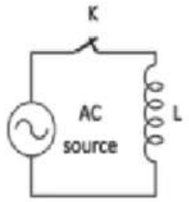


Figure (4 – 5)

AC circuit having an inductor

The figure (4 – 5) illustrates a series circuit containing an AC power supply, a switch and an inductive coil of zero ohmic resistance.

On closing the circuit, the current grows gradually from zero to a maximum value at a rate $\frac{\Delta I}{\Delta t}$. A reverse electromotive force of magnitude $- L \frac{\Delta I}{\Delta t}$ is induced by self-induction across the coil that opposes the change in the

electric current.

The frequency of the induced electromotive force is the same as the frequency of the AC supply but acting in the opposite direction to the electromotive force of the supply.

The instantaneous voltage across the inductor is given by:

$$V = -L\frac{\Delta I}{\Delta t}$$

Given that I varies with the phase angle according to sine curve as indicated in figure (4 – 6 a), the value $\frac{\Delta I}{\Delta t}$ represents the slope of the tangent drawn to the curve. It reaches its peak value when the phase angle equals zero, and then it decreases gradually to reach zero when I reaches its peak value. As the value of current decreases, the slope $\frac{\Delta I}{\Delta t}$ becomes negative. Thus, the curve representing the voltage takes the waveform indicated in figure (4 – 6 a)

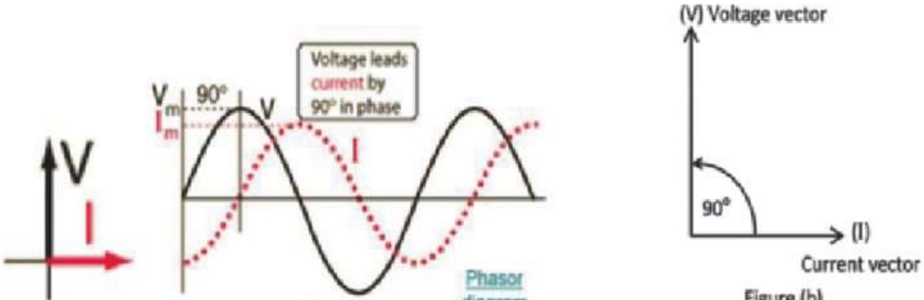


Figure (a)

Figure (b)

Figure (4 – 6)

AC voltage leads AC current in an inductor by 90°

It is obvious that the voltage (V) **leads** the current (I) by a phase angle 90°. Both current and voltage across an inductor can be represented by two vectors as in figure (4 – 6 b).

Finding the inductive reactance in a coil (X_L):

It is found that the inductive reactance in a coil is directly proportional to each of the self-inductance of the coil and the frequency of current passing through it.

The inductive reactance = 2 π x current frequency x self-inductance

$$X_L = 2\pi f L \quad \text{Ohm}$$

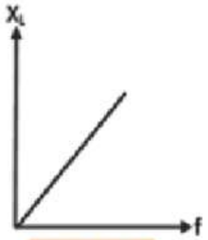


Figure (4 – 7)

Inductive reactance and frequency

What is the inductive reactance?

It is the opposition to the flow of the AC current through a coil due to its self-inductance.

The value of current (I) in an inductor = $\frac{electromotive\ force}{inductive\ reactance}$

The inductive reactance of inductor network:

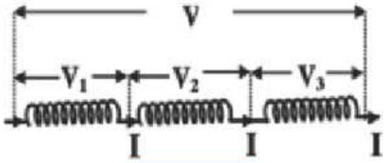


Figure (4 – 8)
Connection of inductors in series

First: If inductors are connected in series:

In this aspect, inductors and resistors are alike:

$$X_L = X_{L1} + X_{L2} + X_{L3}$$

If the inductive reactance for all inductors is equal: $X_L = n\, X_{L1}$

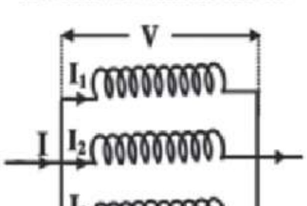


Figure (4 – 10)
Connection of inductors in parallel

Second: If inductors are connected in parallel:

$$\frac{1}{X_L} = \frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}$$

If the inductive reactance for (n) inductors is equal:

$$X_L = \frac{X_{L1}}{n}$$

Example: A coil of self-inductance 700 mH and zero ohmic resistance is connected to an AC supply of electromotive force = 200 V and frequency 50 Hz. Calculate the current value through the coil.

Solution:

$$X_L = 2\pi f L \;= 2 \times \frac{22}{7} \times 50 \times 0.7 = 220\,\Omega$$

$$I = \frac{V}{X_L} = \frac{200}{220} = 0.9\,A$$

3) AC current and AC voltage in a capacitor circuit.

The electric capacitor: in its simplest form is made up of two parallel metal plates separated by an insulator. When the capacitor is charged, one plate is charged positively whereas the other is charged negatively creating a potential difference (V) between them. If the quantity of charge on one of its plates is (Q) and the capacitance of capacitor is (C), the relation between them is given by: $C = \frac{Q}{V}$ where the charge is measured in Coulombs, the voltage in Volts and the capacitance in Farads.

The capacitor in a DC circuit:

When a capacitor is connected to a battery where the plate (A) is connected to the positive pole of the battery while the plate (B) is connected to the negative pole as shown in figure, a negative charge (free electrons) passes from the negative pole to the plate (B), lowering its potential. This negative charge on plate (B) pushes the negative free charges in plate (A) towards the positive pole of the battery charging the plate (A) with a positive charge, and raising its potential.

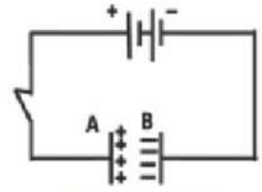


Figure (4 – 11)
A capacitor in DC circuit

When the potential difference between the two plates equates the voltage across the poles of the battery, the flow of charge stops and the capacitor is said to be charged.

This means that a momentary current flows through the circuit then vanishes, meanwhile the capacitor is charged.

Quantity of charge on plates = Capacitance of capacitor x Voltage across plates

The capacitor in an AC circuit:

When a capacitor is connected to an AC power supply, the capacitor is charged up during the first quarter cycle till the potential difference between its plates reaches a maximum value that equates the maximum value of the electromotive force of the supply. As the emf of the supply drops, the larger voltage across the capacitor allows its discharge to the power supply. As the emf of the power supply reaches zero, the capacitor voltage reaches zero, too at the end of the first half cycle.

Likewise in the other half cycle, the capacitor is recharged but with opposite polarity as in figure (4 –12) till the voltage across its plates reaches the maximum value of the electromotive force of the supply. Then, it starts to discharge as the emf of the supply drops till both voltages reach zero at the end of the second half cycle. This succession of charging and discharging is constantly repeated in the other cycles.

Consequently, an AC current can pass through a circuit containing an AC power supply and a capacitor. In other words, the capacitor allows the AC current to flow in the circuit and the instantaneous value of this current is directly proportional to the rate of change of charge on the capacitor, or the voltage across its plates where the charge and the voltage across its plates have the same phase as shown in figure.

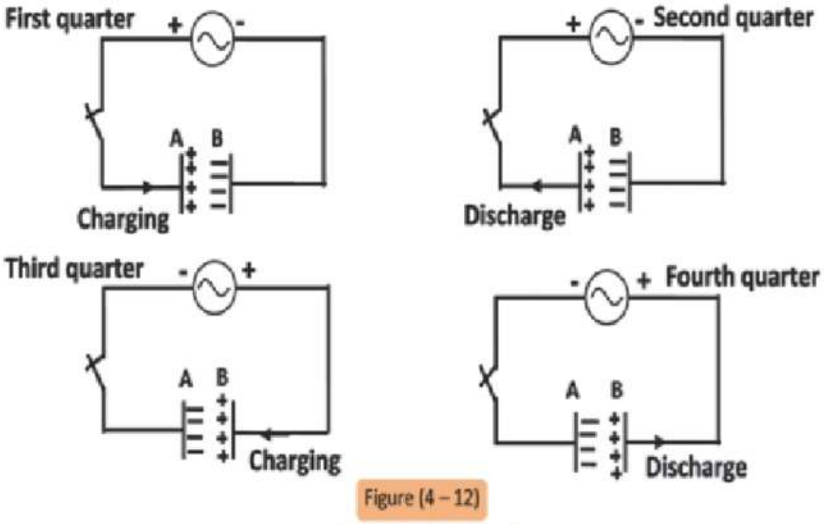


Figure (4 – 12)

A capacitor in AC circuit

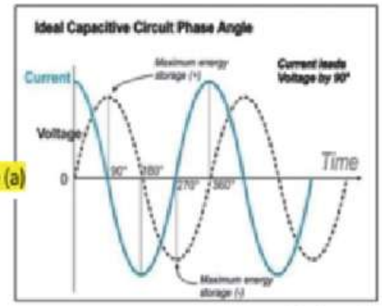
Since $I = \frac{\Delta Q}{\Delta t}$ and $Q = C V$

$$I = C\frac{\Delta V}{\Delta t}$$

Since voltage **V** varies with the phase angle θ as a sine waveform as shown in figure (4 – 13 a), Thus, $\frac{\Delta V}{\Delta t}$ represents the slope of the tangent drawn to the curve. It reaches its peak value when the phase angle equals zero, and then it decreases gradually to reach zero when V reaches its peak value. When V decreases, the slope would have a negative value and the instantaneous values of current, as well. Thus, the curve representing I takes the waveform indicated in figure (4 – 13 a)

It is obvious that the voltage **lags** the current by a phase angle 90°. Both current and voltage across a capacitor can be represented by two vectors as in figure (4 – 13 b).

Figure (a)



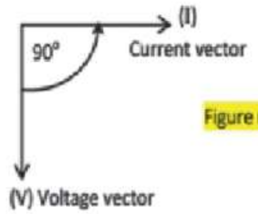


Figure (b)

Figure (4 – 13)

AC voltage lags AC current in a capacitor by 90°

The capacitive reactance in a capacitor (X_C) is given by the relation:

$X_C = \frac{1}{2\pi f C}$ Ohm, where (f) is the current frequency.

What is the capacitive reactance?

It is the opposition to the flow of AC current in a capacitor due to its capacitance.

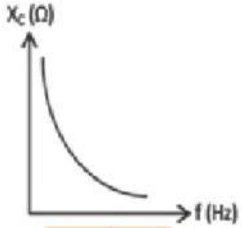


Figure (4 – 14)

The capacitive reactance and frequency

Connection of Capacitors:

First: If capacitors are connected in series as shown in figure, they are charged equally with a charge Q.

$$V = V_1 + V_2 + V_3$$

$$\frac{Q}{C} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3}$$

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

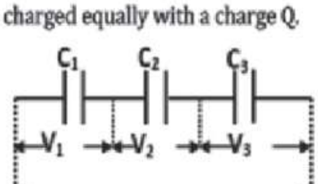


Figure (4 – 15)

Capacitors in series

If the capacitance is the same for (n) capacitors,

$$C = \frac{C_1}{n}$$

Second: If capacitors are connected in parallel, the voltage across each capacitor is the same:

$$Q = Q_1 + Q_2 + Q_3$$

$$V\,C = V\,C_1 + V\,C_2 + V\,C_3$$

$$C = C_1 + C_2 + C_3$$

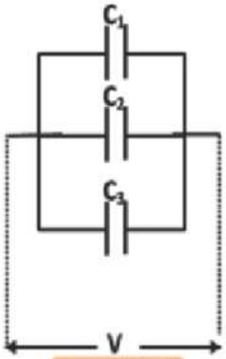


Figure (4 – 16)
Capacitors in parallel

If the capacitance is the same for (n)capacitors,

$$C = n\,C_1$$

Example: Three capacitors of capacitance 20, 80 and 40 microfarad are connected in parallel then to an AC supply of electromotive force = 100 V and frequency 50 Hz. Calculate the value of current flowing through the circuit.

Solution:

$$C = C_1 + C_2 + C_3 = 20 + 80 + 40 = 140\ \mu F = 1.4 \times 10^{-4}\ \text{Farad}$$

$$X_C = \frac{1}{2\pi f C} = \frac{1 \times 7 \times 10^4}{2 \times 22 \times 50 \times 1.4} = 22.72\ \Omega$$

$$I = \frac{100}{22.72} = 4.4\ A$$

Impedance:

In an electric circuit containing an AC power supply together with inductive coils, capacitors, and resistors, the AC current would be opposed by reactance in addition to resistance of resistors and wires.

This combined opposition will be a vector combination of resistance and reactance which is known as **impedance,** its symbol is "Z".

4) AC circuit contains ohmic resistance and inductive coil in series (RL-circuit):

It is almost impossible to construct an inductive coil with zero resistance. The coil must have resistance. We may distinct resistance from inductive reactance of the same coil as shown in figure (4 – 17)

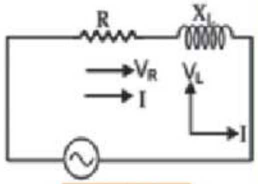


Figure (4 – 17)
RL circuit

To find the total voltage across them, phasor diagrams are used. The same current passes through both of the resistance and the coil since they are connected in series, but total voltage **V** and the current are out of phase.

That is because voltage and current in the resistance are in phase while voltage in the coil leads current by a phase angle 90°.

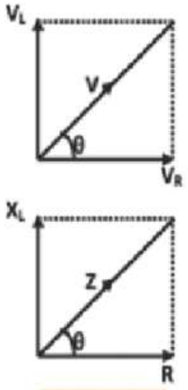


Figure (4 – 18)
Impedance of RL circuit

The total voltage **V** can be determined by the relation:

$$V = \sqrt{V_R^{\ 2} + V_L^{\ 2}}$$

$$\tan\theta = \frac{V_L}{V_R} = \frac{X_L}{X_R}$$

Since, $V_R = I\,R$ *and* $V_L = I\,X_L$

$$Z = \sqrt{R^2 + X_L^{\ 2}}$$

Example: An AC power supply of emf 80 V and frequency 50 Hz supplies a current to a coil of self-inductance $\frac{21}{220}$ *Henery* and a resistance 40 Ω in series. Find:

1- Impedance.

2- The voltage across each of the resistance and the coil. Is it correct to add these voltages algebraically?

Solution:

The inductive reactance: $X_L = 2\pi f L = 2 \times \frac{22}{7} \times 50 \times \frac{21}{220} = 30\Omega$

Impedance: $Z = \sqrt{R^2 + X_L^{\ 2}} = \sqrt{(40)^2 + (30)^2} = 50\,\Omega$

$$I = \frac{V}{Z} = \frac{80}{50} = 1.6\,A$$

$$V_R = 40 \times 1.6 = 64\,V$$

$$V_L = 30 \times 1.6 = 48\,V$$

The algebraic sum of these voltages: $V = 64 + 48 = 112\,V$

This value is greater than the emf of the power supply. Because of this, voltages in the AC circuit are not added together algebraically.

But by vector addition:

$$V = \sqrt{V_R^{\ 2} + V_L^{\ 2}} = \sqrt{(64)^2 + (48)^2} = 80\,V$$

5) AC circuit contains ohmic resistance and capacitors in series (RC-circuit):

The same current passes through the resistance and the capacitor since they are connected in series. To find the total voltage **V**, we consider that:

Voltage and current in the resistance are in phase while the voltage in the capacitor lags the current by a phase angle 90°

The total voltage V can be determined by the relation:

$$V = \sqrt{V_R^2 + V_C^2}$$

$$\tan\theta = \frac{-V_C}{V_R} = \frac{-X_C}{X_R}$$

Since, $V_R = I\,R$ *and* $V_C = I\,X_C$

$$Z = \sqrt{R^2 + X_C^2}$$

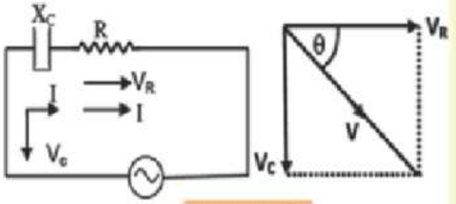


Figure (4 – 19)

RC circuit

6) AC circuit contains ohmic resistance, inductor and capacitors in series (LCR-circuit):

The current passing through the resistance, the inductor and the capacitor is the same since they are connected in series. On the other hand, the phase of voltage across each component is different from one component to another.

In the ohmic resistance, voltage is in the same phase with current.

In the inductor, voltage leads current by a phase angle 90°

In the capacitor, voltage lags current by a phase angle 90°

And the resultant of voltage vectors is given by:

$$V = \sqrt{V_R^2 + (V_L - V_C)^2}$$

Dividing by I:

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

$$\tan\theta = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$$

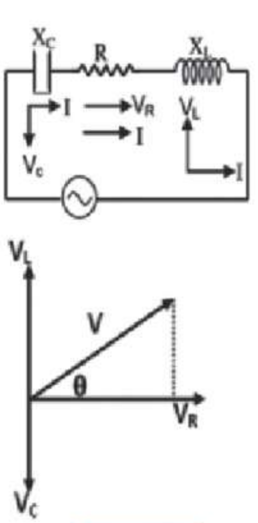


Figure (4 – 17)

LCR circuit

Note that:

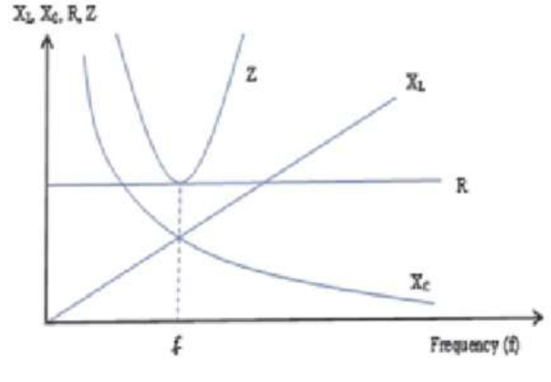
1- If $X_L > X_C$, tan of the phase angle is positive and the circuit behaves as an inductive circuit. In other words, the voltage leads the current by a phase angle θ

2- If $X_L < X_C$, tan of the phase angle is negative and the circuit behaves as a capacitive circuit. In other words, the voltage lags the current by a phase angle θ

3- If $X_L = X_C$ the phase angle = zero and the circuit behaves as an ohmic resistance. In other words, the voltage and the current have the same phase.

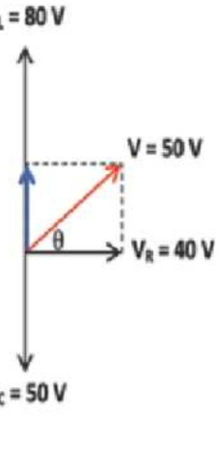
4- Inductive reactance in the coil and capacitive reactance in the capacitor do not consume any electric power because the energy (power) is stored either as an electric field in the capacitor that transfers it back to the power supply on discharge or a magnetic field in the coil. The power consumed in the circuit is only the power that is consumed due to the ohmic resistance.

The relation between each of resistance, reactance and impedance and the current frequency



Example: A current of 2 A passes through a series AC circuit containing a coil, a capacitor and a resistor. If the voltage across each of the coil, the capacitor and the resistor are 80 V, 50 V and 40 V respectively,

1- Sketch voltage vectors, and then calculate the total voltage across the power supply.
2- Find the phase angle between total voltage and current. Describe the behavior of the circuit?
3- Find the power consumed as heat energy in the circuit.
4- Find the circuit impedance.



Solution

1- $V = \sqrt{V_R^2 + (V_L - V_C)^2} = \sqrt{(40)^2 + (80-50)^2} = 50\ V$

2- $\tan\theta = \frac{V_L - V_C}{V_R} = \frac{80-50}{40} = \frac{3}{4}$

$\theta = 37^\circ$ The circuit behaves as an inductive circuit

3- The resistance $(R) = \frac{V_R}{I} = \frac{40}{2} = 20\ \Omega$

The consumed power in the circuit = $I^2 R = (2)^2 \times 20 = 80\ W$

4- $Z = \frac{50}{2} = 25\ \Omega$

Oscillating circuit

"Interchange of the energy stored in the inductive coil as a magnetic field and in the capacitor as an electric field"

The oscillator circuit consists of an inductive coil of negligible ohmic resistance and a capacitor connected together through a switch (b) as shown in figure (4 – 18)

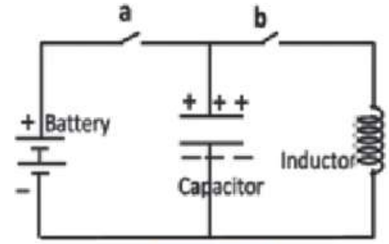


Figure (4 – 18)
Oscillator circuit

1- When the switch (a) is turned on, a momentary current passes from the battery to charge up the capacitor; the plate connected to the positive pole becomes positively charged while the plate connected to the negative pole becomes negatively charged. Then, the current stops flowing. An electric field is built up between the capacitor plates storing energy as electric energy. When the switch (a) is turned off, the capacitor remains charged.

2- Meanwhile the switch (a) is off, the switch (b) is turned on, the capacitor discharges its charge through the inductive coil and therefore a momentary current passes from the positive plate to the negative plate. The voltage across the capacitor collapses and therefore the electric field between its plates vanishes. The flowing current through the coil generates a magnetic field that stores the energy that has been in the capacitor before as electric energy.

3- Initially, there is a high rate of current flowing through the coil due to the high voltage across the capacitor plates. As this rate of current fades gradually, a forward current is induced in the coil by self-induction that draws more charges from the positive plate of the capacitor towards the negative plate.
Consequently, the plate that was negatively charged becomes positive while the other plate becomes negative reversing the capacitor polarity, generating an electric field between them.
The current through the coil ceases and therefore the magnetic field till they vanish. Accordingly, The energy stored in the coil as a magnetic field is transformed into electric energy stored in the capacitor.

4- Next to that, the capacitor discharges another time through the coil in a direction opposite to original discharge. Thus, charging and discharging of the capacitor is cycled and an electric oscillation of high frequency is produced in the circuit, interchanging the energy alternately between the two fields.

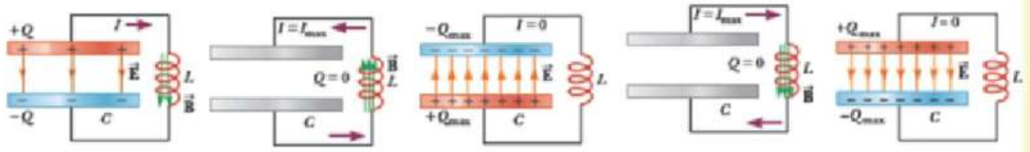


Figure (4 – 19)
Interchange of stored energy between an inductive coil and a capacitor in the oscillating circuit

5- Due to the ohmic resistance in the coil and the other circuit wiring, a part of energy is dissipated as heat energy. This result in a gradual decrease in the value of the alternating current in the circuit and the voltage across the capacitor plates, as well. This hinders charging and discharging processes and causes the current eventually to die away to zero. However, if this loss is compensated by extra charges supplied to the capacitor, the oscillatory action of passing energy back and forth between the capacitor and the inductor would continue indefinitely.

The diagram (4 – 20) illustrates a damping oscillation due to ceasing of charge on capacitor plates over time.

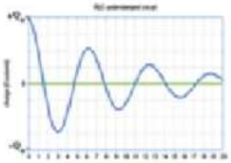


Figure (4 – 20)
Damping oscillation

Finding the current frequency in the oscillator circuit:

In the oscillator circuit, when capacitive reactance and inductive reactance are equal and cancel out each other, leaving only the resistance of the circuit to oppose the flow of current, the current reaches its maximum in the circuit. The circuit frequency can be deduced as follows:

$\because X_L = X_C \qquad \therefore 2\pi f L = \frac{1}{2\pi f C}$

The circuit frequency: $f = \frac{1}{2\pi\sqrt{LC}}$ Hz

We can substitute self-inductance **L** by the relation: $L = \frac{\mu A N^2}{\ell}$

Question: Through the above mentioned relation, what are the factors that affect the frequency in the oscillator circuit?

Example 1: Find the frequency of current in an oscillator circuit if self-inductance of the coil is 16 μH and the capacitor capacitance is 4.9 mF.

Solution:

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{7}{2 \times 22}\sqrt{\frac{1}{16 \times 10^{-6} \times 4.9 \times 10^{-3}}} = \frac{7}{44} \times \frac{10^5}{4 \times 7} = 568.18\ Hz$$

Example 2: When an inductive coil is connected to a capacitor of capacitance 18 microfarad, the frequency of the circuit is $2 \times 10^4\ Hz$. But, when the same coil is connected to another capacitor, the frequency of the circuit becomes $3 \times 10^4\ Hz$. Calculate the capacitance of the second capacitor.

Solution:

$\because f \propto \frac{1}{\sqrt{C}} \qquad \therefore \frac{f_1}{f_2} = \sqrt{\frac{c_2}{c_1}}$

$\therefore \frac{2 \times 10^4}{3 \times 10^4} = \sqrt{\frac{c_2}{18}} \qquad \therefore \frac{4}{9} = \frac{c_2}{18} \qquad c_2 = 8\mu H$

Tuned or "Resonant" Circuit

It is an electric circuit consisting of a capacitor of variable capacitance connected to an inductor whose inductance can be altered.

The most common application of resonant circuits is **tuning** radio receivers for picking out the signal of a particular station,at a particular frequency.

Operation of resonant circuit:

Connect a circuit of an AC power supply of varying frequency, a capacitor of variable capacitance, an inductor and hot wire ammeter as shown in figure (4 – 21).

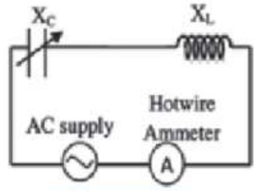


Figure (4 – 21)
Tuned circuit

Allow the current to pass and vary the frequency of the AC supply. You find that the current value changes. The current value is low if there is a big difference between frequency of the power supply and the circuit frequency. On the other hand, the current value increases as the frequency of the power supply approaches the circuit frequency. The current value reaches its maximum when the circuit frequency resonates with the source frequency. Hence, the inductive reactance should be equal to the capacitive reactance. Resonating the circuit frequency with the source frequency can be achieved either by tuning the source frequency, the capacitor capacitance or the coil inductance.

Resonance in tuned circuit and resonance in sound are alike. Intensity of sound strengthens when two tuning forks vibrate at the same frequency, and weakens when their frequencies differ markedly.

Conclusion: If multiple frequencies affect an oscillator circuit at the same time, the circuit does not allow a current to pass except for that having frequency either equal or so close to the circuit frequency. In this case the circuit is said to be resonant.

Tuned "resonant" circuit in the wireless radio receivers:

In radio receivers, the tuned circuit is connected to the antenna that is hit by electromagnetic waves transmitted by different stations; each of a different frequency. The wave that has a frequency equal to the circuit frequency only affects the antenna and generates a current in the tuned circuit of equal frequency to that particular station.

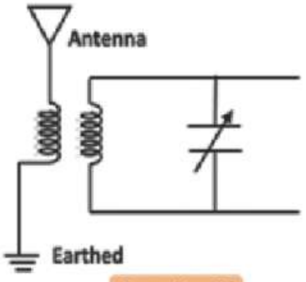


Figure (4 – 22)
Tuned circuit in radio receivers

Thus, the tuned circuit in radio receivers allows only the current that has frequency equal to the circuit frequency to pass. When you like to hear a certain broadcast station, you tune the frequency of the circuit either by altering the capacitor capacitance or the number of turns in the coil to allow only a current to pass if its frequency resonates with the circuit frequency. This current then undergoes processes of amplification, rectification and finally the current expressing the sound is separated to pass to loudspeakers.

In a Nutshell

1. The alternating current: is the current that changes its intensity periodically from zero to a maximum value, then drops back to zero in a half cycle. As it reverses its direction in the other half cycle, its intensity increases to maximum then back to zero value.

2. Hot wire ammeter: is the instrument used to measure either the effective value of the AC current or the intensity of direct current, based on the expansion of iridium-platinum wire due to the thermal effect of current.

3. Inductive reactance of a coil: is the opposition to the flow of the AC current in a coil due to self-inductance.

   $X_L = 2\pi f L$ Ohm

4. The inductive reactance of inductors connected in series: $X_L = X_{L1} + X_{L2} + X_{L3}$

5. The inductive reactance of inductors connected in parallel: $\frac{1}{X_L} = \frac{1}{X_{L1}} + \frac{1}{X_{L2}} + \frac{1}{X_{L3}}$

6. Capacitive reactance in a capacitor: is the opposition to the flow of AC current in a capacitor due to its capacitance.

   $X_C = \frac{1}{2\pi f C}$ Ohm

7. The capacitive reactance of inductors connected in series: $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

8. The capacitive reactance of inductors connected in parallel: $C = C_1 + C_2 + C_3$

9. Impedance of circuit: is the equivalent of reactance and resistance in the circuit.

   $Z = \sqrt{R^2 + (X_L - X_C)^2}$

10. The frequency of the resonant circuit:

    $f = \frac{1}{2\pi\sqrt{LC}}$

Questions and Drills

Q1: What is meant by each of the following...?

The inductive reactance – The capacitive reactance – Impedance – The oscillator circuit

Q2: Mention the factors that affect each of:

1- The inductive reactance 2– The capacitive reactance

3 – Frequency of an oscillator circuit 4– The impedance

Q3 : How is the total capacitance calculated for a number of capacitors connected together:

a) In series b) In parallel

Q4 : Describe the construction of the oscillator circuit and explain its operation.

Q5 : Describe the construction of the tuned circuit and explain its operation in the radio receiver device.

Q6: Find the total capacitance of two capacitors of capacitance 24 and 48 microfarad connected together:

a) In series b) In parallel

Q7: AC current of frequency 50 Hz passes through a resistor 12 Ω and an inductor of inductance $\frac{7}{440}$ *Henry* connected together in series. Find impedance of the circuit. (13 Ω)

Q8 : Calculate the value of current passing through an inductive coil of self-inductance $\frac{7}{275}$ *Henry* and ohmic resistance 6 Ω if the coil is connectedto:

a) A direct power supply of emf 6 Volt and negligible internal resistance.

b) An alternating power supply of emf 6 Volt and frequency 50 Hz. (0.6 A , 1 A)

Q9: Three identical capacitors, of capacitance 14 microfarad each, are connected in parallel then to a power supply of frequency 50 Hz. Calculate the total capacitive reactance.

Q10 : A resistor of 6 Ω, a capacitor of capacitance and a coil of self-inductance 0.28 Henry are connected together in series to an AC power supply of voltage 20 V and frequency 50 Hz. Find:

a) The potential difference between the capacitor plates.
b) The phase angle between the total voltage and current.
c) The maximum of the current value that can be reached in the circuit.

(160 V , 53^{o} , 2.8 A)

Q11: A tuned circuit in a radio receiver consists of an inductive coil of inductance 10 millinery, a resistance 50 Ω and a capacitor of variable capacitance. Wireless waves of frequency 980 kHz hit the antenna and generate a voltage 10^{-4} Volt across the circuit. Find the capacitor capacitance and the current value at resonance.

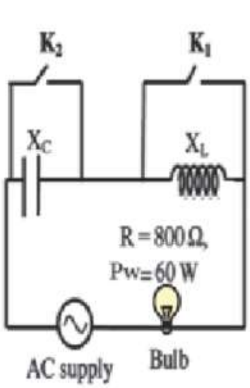
(2.635×10^{-12} F , 2×10^{-6} A)

Q12: A series circuit consists of a coil of inductive reactance 250 Ω, a resistance 100 Ω, a capacitor of variable capacitance and AC power supply of electromotive force 200 Volt and frequency $\frac{1000}{44}\,Hz$. Given that the current through the circuit reached its maximum value, find:

a) The capacitive reactance that caused the current to reach its maximum.
b) The potential difference between the terminals of the coil and the capacitor plates in this case.

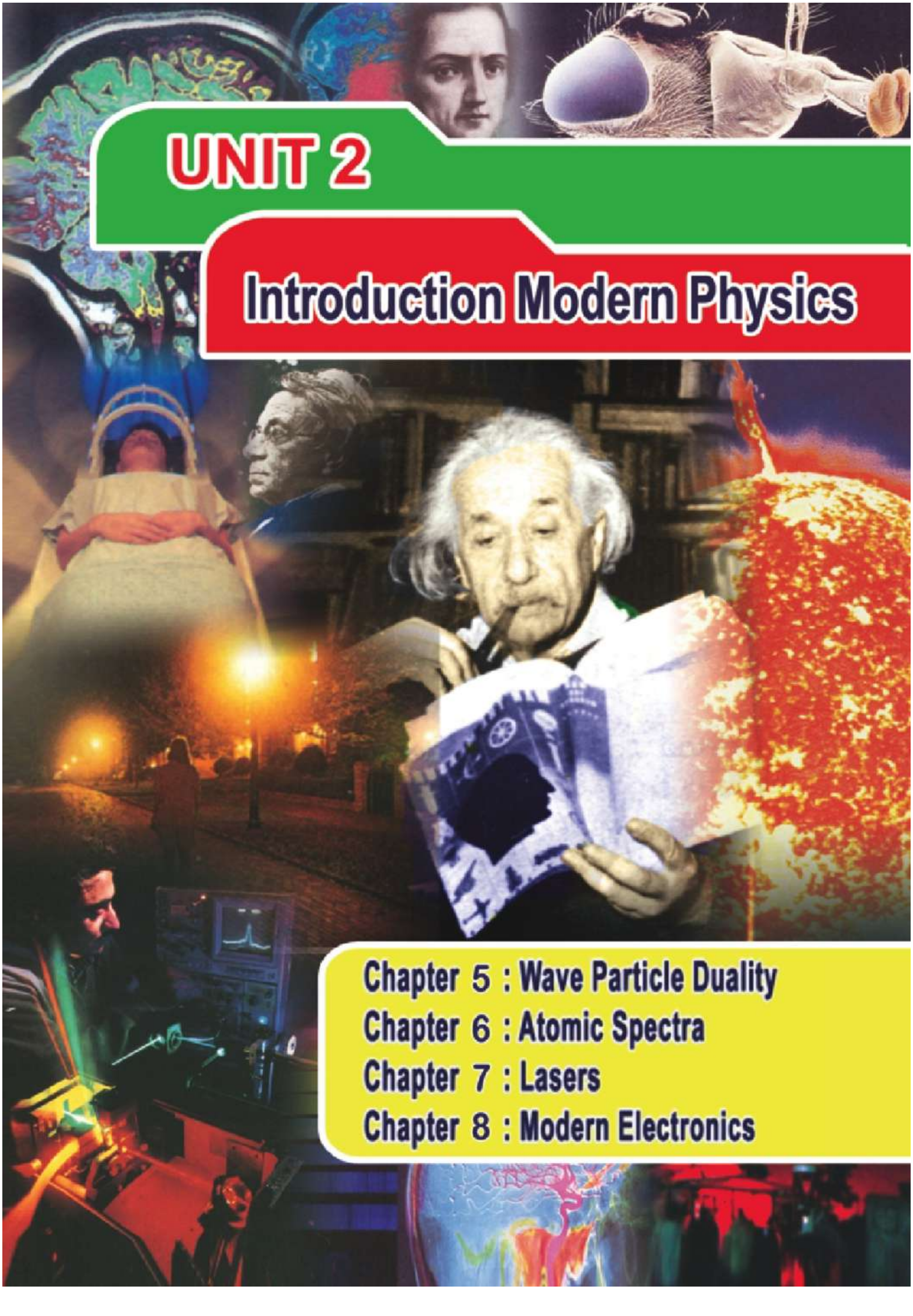
(28×10^{-6}F , 500 V)

Q 13 : The circuit illustrated in figure contains an AC supply of frequency 50 Hz and electromotive force 220 Volt, a capacitor of capacitance 4 microfarad and an inductor of inductance 2.53 Henry. Find:



1- The capacitive reactance.
2- The inductive reactance.
3- What happens to the glowing of the electric bulb when only K_1 is turned on? Find the impedance.
4- What happens to the glowing of the electric bulb when only K_2 is turned on? Find the impedance.
5- What happens to the glowing of the electric bulb when both K_1 and K_2 are turned on? Find the impedance.

(795.4 Ω, 795.4 Ω, 1128 Ω)



UNIT 2

Introduction Modern Physics

Chapter 5 : Wave Particle Duality
Chapter 6 : Atomic Spectra
Chapter 7 : Lasers
Chapter 8 : Modern Electronics

Chapter 5   Wave Particle Duality

Overview

All what we have studied so far can be lumped under the title of classical physics. By classical, we do not mean outdated or obsolete. In fact, classical physics explains everything in our daily life and our common experiences. The present unit, however, entails some of the basic concepts of modern physics and a general view of a quantum physics. This branch of physics (modern or quantum) deals with a great collection of scientific phenomena which might not be directly observed in our daily life, but treat a number of situations in the universe which classical physics cannot explain, especially when we deal with atomic and subatomic systems, i.e, down to the subatomic scale .

Also, this kind of physics explains all phenomena involved in electronics which is the basis for all modern electronic and communication systems. It also explains chemical reactions on the level of the molecule. Some of such reactions were photographed by Ahmed Zewail using a high speed laser camera. Such work entitled him to earn the Noble Prize in chemistry in1999.

Blackbody Radiation:

We are content so far to regard light as waves. Waves have common features, i.e,

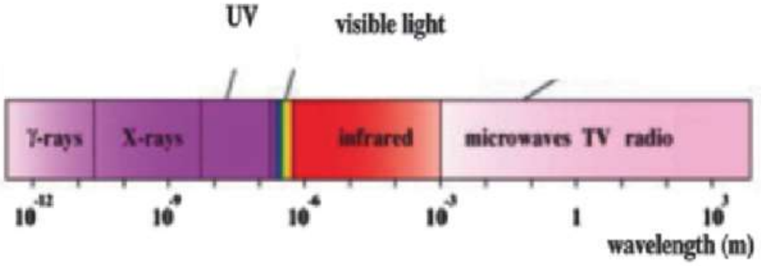


Fig (5-1)
Electromagnetic spectrum

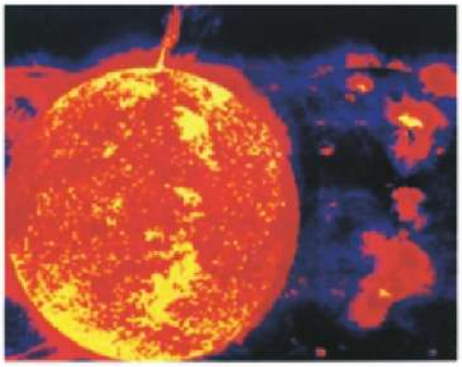


Fig (5-2)
The Sun as a source of em radiation

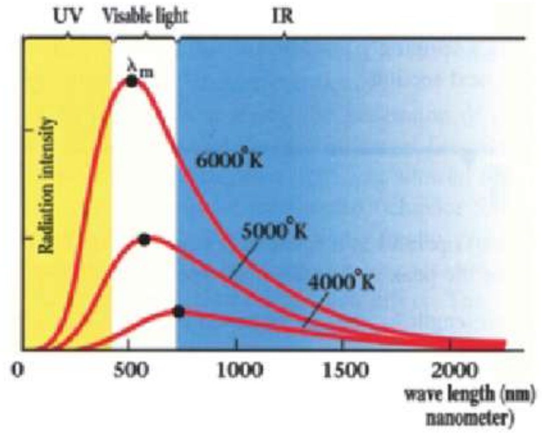
Fig (5-3)
A burnig charcoal emits em radiation

Fig (5-4a)
A glowing incandescent lamp emits em radiation

Fig (5-4b)
A lamp emitting less em radiation

reflection, refraction, interference and diffraction. We know also that visible light is but a small portion of the electromagnetic (em) spectrum (Fig 5-1). Electromagnetic waves may differ in frequency, and hence, in wavelength, but they propagate in free space at a constant speed $c = 3 \times 10^8$ m/s. Electromagnetic waves do not need necessarily a medium to propagate in. We all observe that hot bodies emit light and heat. An example is the Sun (Fig

5-2) and other stars, a burning charcoal (Fig 5-3) and a glowing incandescent lamp (Fig 5-4). We also note that the dominant color of light emitted from these sources varies. Hence,an em source does not emit all wavelengths equally, but the intensity of radiation varies with wavelength. The distribution of the radiation intensity with wavelength is called Planck's distribution (Fig 5-5). It was also found that the wavelength λ_m at which the peak of the curve occurs is inversely proportional to temperature. This is known as Wien's law. Therefore, the higher the temperature, the smaller the wavelength of the peak . We also note that as the wavelength tends to infinity (very large)or to zero (very small) the intensity of radiation tends to zero. For example, the temperature at the surface of the Sun is 6000°K. Hence, the wavelength at the peak is 5000°A (0.5 μm). This is within the visible range. Thus, almost 40% of the total energy emitted by the Sun is in the visible range and almost 50% is heat (infrared radiation), while the rest is distributed over the remaining spectrum. We practically obtain the same shape of radiation intensity distribution for a glowing incandescent lamp, except that the temperature is now 3000°K which puts the wavelength at the peak at 1000 nm = 10^{-6} m = 10000°A = 1 Micron. From such lamps we get nearly 20 % as visible light and most of the rest as heat.



Fig(5-5)

The wavelength at the peak is inversely proportional to temperature

We cannot explain these observations using classical physics. It can be argued from

classical physics that since the radiation is an em wave, the intensity of radiation increases with frequency. Why then should the intensity of radiation go down at the high frequency end, (Fig 5-6)? This curve is repeated for all hot bodies which emit continuous radiation not only the Sun but also the Earth, and all bodies even living creatures. But the Earth- being a non glowing body - it absorbs the radiation from the Sun and reemits it. But its temperature is far less than that of the Sun. Therefore, we find the wavelength at the peak to be nearly 10 Micron ,which is within the infrared region (Fig 5-7).There are satellites, and airborne as well as terrestrial equipment which map and photograph the surface of the Earth, using different regions of the spectrum including the infrared radiation emitted by the surface of the Earth ,in addition to the reflected visible light (Fig 12-8). Also, microwaves are used for the same purpose in radars. Scientists analyze such images to determine possible natural Earth resources.

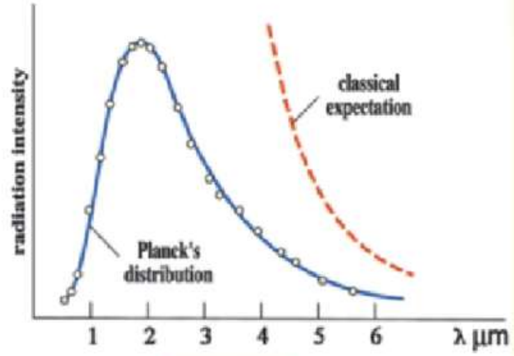


Fig (5-6)

Radiation decreases with increasing frequency in disagreement with classical expectations

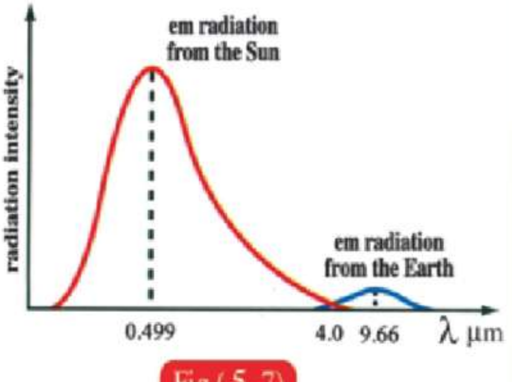


Fig (5-7)

Radiation from the Earth and from the Sun

This technique is also used for military purposes such as night vision systems, which detect and image moving objects in the dark due to the heat radiation which these objects re- emit (Figs 5-9, 5-10). Thermal imaging is also used in medicine, particularly in

tomography (tumor detection) (Fig 5-11), in embryology and in criminology, since the heat radiated from a person lingers for a while even after the person has left. All these applications are called remote sensing. Egypt has been a pioneer in this field. How can we explain the bell shape of radiation? Planck in 1900 came up with the answer.

Fig (5-8)
An image of southern Sinai taken by Land sat satellites

Planck called this phenomenon black body radiation. The reason for naming it so is that a black body absorbs all radiation falling on it, regardless of the wavelength. It is, thus, a perfect absorber. It then re-emits this radiation wholly. It is therefore a perfect emitter.

If we imagine an enclosed cavity with a small hole, the inside of the cavity appears black because all of the radiation within the cavity remains trapped due to multiple reflections. Only a small part of it leaks out, which is called blackbody radiation (Fig 5-12).

Planck managed to explain this blackbody phenomenon with an interpretation that

Fig (5-9)
A night vision system

Fig (5-10)
An image taken by a night vision system

sounded weird at the time. He proposed that radiation was made up of small units (or packets) of energy, each he called quantum (or photon). Therefore, we may consider radiation from a glowing object as a flux of emitted photons. The photons' energy increases with frequency, but their number decreases with increasing energy.

Fig (5-11)
A thermal image for the face and neck

The photons emanate from the vibrations of atoms. The energy of these vibrating atoms is not continuous but quantized (discrete or discontinuous) into levels. These energy levels take values E=nhν, where h is Planck's constant $h=6.625\times10^{-34}$ Js, and ν is the frequency (Hertz - Hz). The atom does not radiate as long as it remains in one energy level. But if the vibrating atom shifts from a high energy level to a lower energy level, it emits a photon whose energy E = hν. Thus, photons with high frequency have high energy and those with low frequency have low energy. Radiation consists of billions upon billions of these photons. We do not see separate photons, but we observe the features of the stream of photons as a whole. These features express in, the stream of photons represent the classical properties of radiation Fig (5 -13) shows an

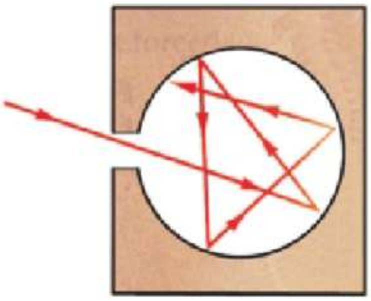


Fig (5 -12a)
Radiation inside the cavity is trapped so it appears black

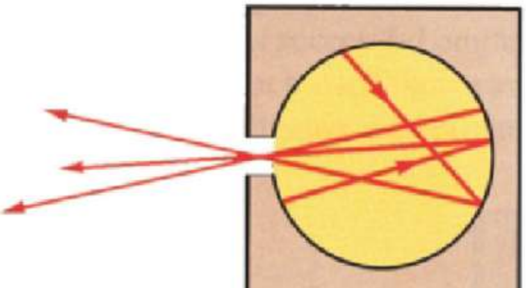


Fig (5 -12b
A small part of energy leaks out of the hole which is called blackbody radiation

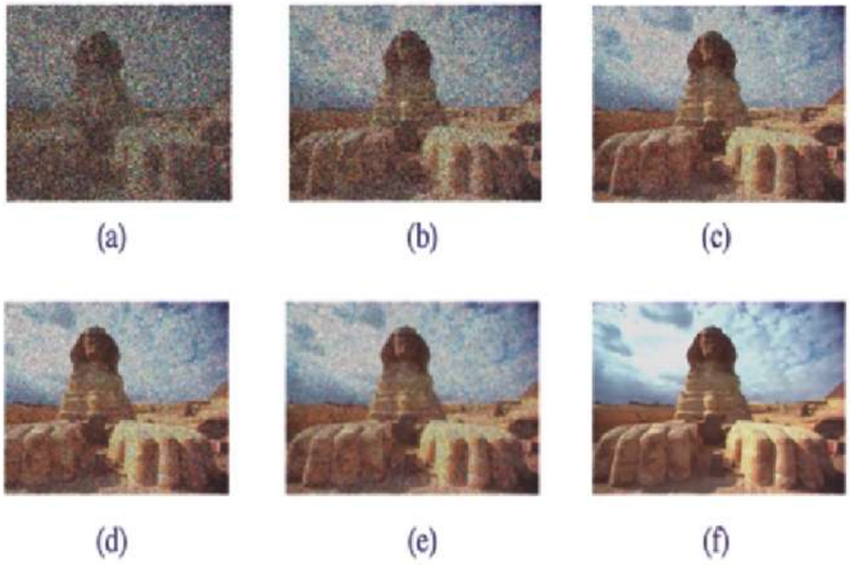


Fig (5 -13)
An image where each shot has a different number of photons in increasing order from(a) to(f)

image taken for an object for different numbers of photons. It is worth mentioning though that the human eye is so sensitive that it can detect as little as one photon falling on it.

Photoelectric Effect and thermoionic effect:

A metal contains positive ions and free electrons which can move around inside the metal but cannot leave it, due to the attractive forces of the surface which may be represented by a surface potential barrier. But some of these electrons can escape if given enough energy in the form of heat or light (Fig 5 -14).

This is the idea behind the cathode ray tube (CRT), which is used in TV and computer monitors (Fig 5 -15).

This tube consists of metal surface called the cathode, which is heated by a filament. Electrons are, thus, emitted by the so called electron gun (E-gun). Due to heat, some electrons may overcome the forces of attraction at the surface. These electrons are then freed (liberated) from the metal and are then picked up by the screen, which is connected

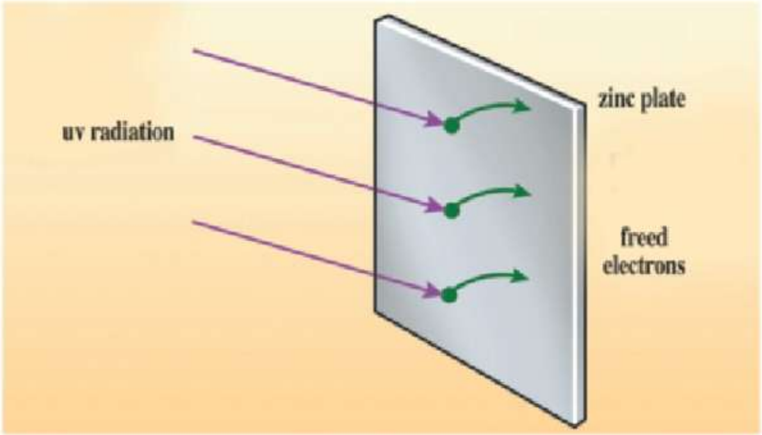


Fig (5 -14a)
Electrons may be freed from a metal if given sufficient energy

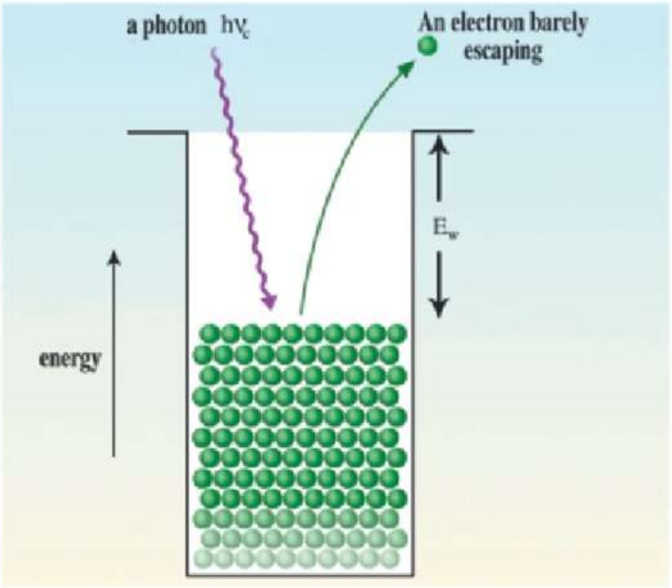


Fig (5 -14b)
Minimum energy needed to free an electron is called work function

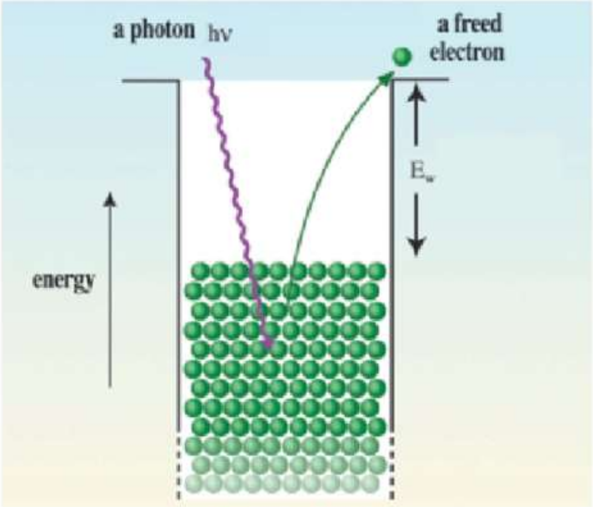


Fig (5-14c)
A more tightly bound electron needs higher energy to escape

to a positive pole called the anode, thus causing current in the external circuit. When the electrons hit the screen, they emit light which varies in intensity from point to point on the fluorescent screen, depending on the intensity of the electrical signal transmitted. Such a signal controls the intensity of the electron beam emitted from the E -gun through a negative grid in its way.

The E -beam can be controlled by electric or magnetic fields to sweep the screen point by

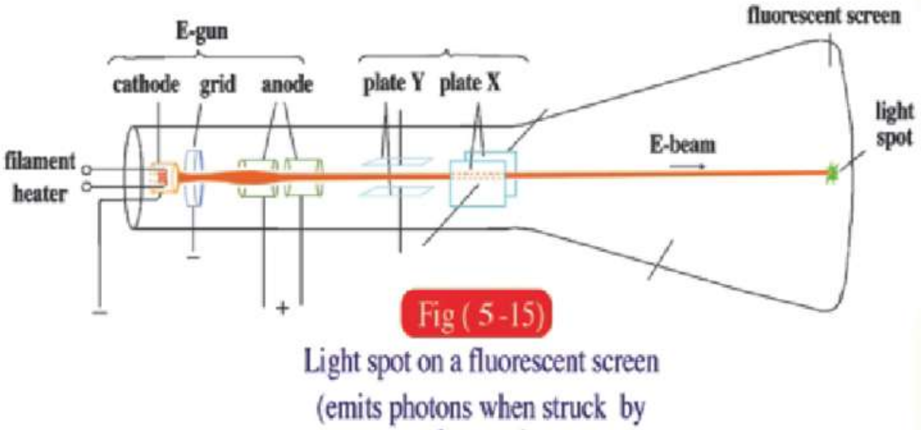


Fig (5-15)
Light spot on a fluorescent screen (emits photons when struck by electrons)

point generating the picture,so called raster until the frame is completed (Fig 5 -15).

When light falls on a cold cathode instead of heating a filament, a current flows in the circuit too. This means electrons have been freed due to light. The emission of such electrons due to light falling on a metallic surface is a phenomenon called photoelectric effect (Fig 5 -16). This phenomenon cannot be explained by the classical theory of light. Considering light as a wave, part of the light falling on the surface of the metal is absorbed, giving some electrons enough energy to escape. We are then up aganist certain difficulties with the classical theory. If we attempt using the classical model, the current intensity or the emission of such electrons (called photoelectrons) should depend on the intensity of the incident wave, regardless of its frequency. Also, the kinetic energy (or velocity) of the emitted electrons should increase with increasing intensity of the incident radiation. Even in the case of low light intensity, giving sufficient time should give some electrons enough energy to be freed, regardless of the frequency of the incident light. But the practical observations are contrary to these classical expectations. It has been observed that the emission of electrons depends primarily on the frequency of the incident light not on its intensity. Such electrons are not emitted if the frequency is under a threshold (critical value) ν_c no matter how intense light may be. If the frequency exceeds ν_c, photocurrent increases with the intensity of light (Fig 5 -17). Also, the kinetic energy (or velocity) of the emitted electrons depends on the frequency of the incident wave not its intensity.In addition, the emission of electrons occurs instantly as long as $\nu > \nu_c$. The electrons do not need time to collect energy if the light intensity is low, provided $\nu > \nu_c$.

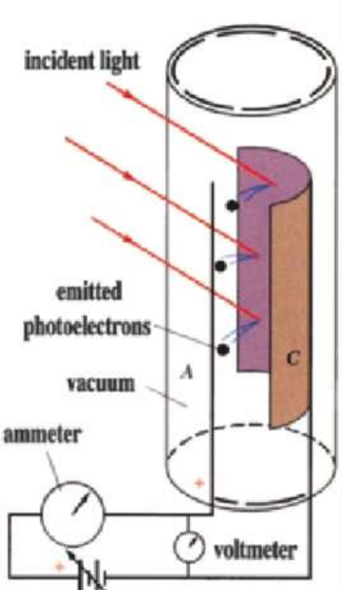


Fig (5-16)
Photoelectric current achieved by absorbing photons on a metal surface
(Photo electeric cell)

Einstein put forth an interpretation for all this, which led him to Nobel prize in 1921. He proposed that a photon with $\nu > \nu_c$ falling on a metallic surface , has energy $h\nu$, while the energy needed to free an electron (called the work function) is $E_w = h\nu_c$ (Fig 5 -14).

Thus, the photon is barely able to free an electron, if it has energy $h\nu = h\nu_c = E_W$. If the photon energy exceeds this limit, the electron is freed and the energy difference

$h\nu - E_W$ is carried by the electrons as kinetic energy, i.e., it moves faster as $h\nu$ increases. Whereas if $h\nu < Ew$, the electron would not be emitted at all, no matter how intense the light might be. Also, the emission is instantaneous. There is no need for time to collect energy. The emission takes place instantly, once $h\nu > h\nu_c$.

It is to be noted that ν_c and E_W vary for different materials, and do not depend on the light intensity, the exposure time or the voltage difference between the anode and the cathode.

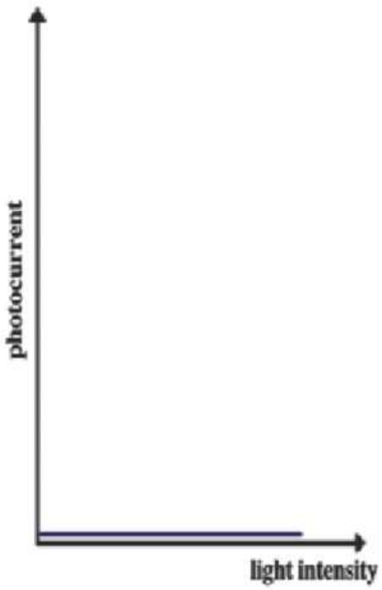


Fig (5-17a)
Photocurrent versus light intensity for $\nu < \nu_c$

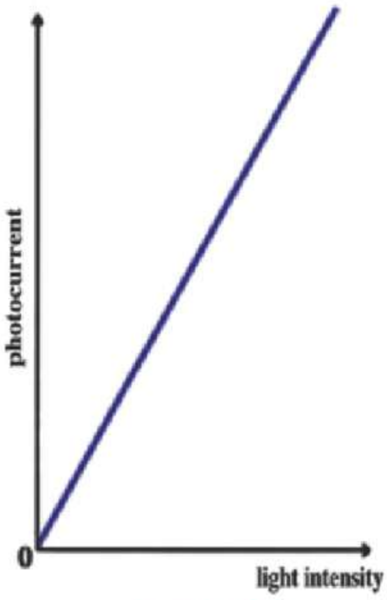


Fig (5-17b)
Photocurrent versus light intensity for $\nu > \nu_c$

Compton Effect

It was observed that when a photon (X or γ rays) collided with a free electron, the photon frequency decreased and changed its direction. Also, the electron velocity increased and it changed its direction (Fig 5 -21). This observation could not be explained by the wave (classical) theory of light. It can be argued based on Planck's hypothesis that electromagnetic radiation consists of photons which can collide with electrons as billiard balls collide. In this collision, linear momentum must be conserved (law of conservation of linear momentum), i.e., the linear momentum before collision must equal the linear momentum after collision. Also, the law of conservation of energy must apply, i.e., the the sum of the energy of the photon and the electron after collision must equal the sum of the energy of the photon and the electron before collision . We must, therefore, consider a photon as a particle with a linear momentum, i.e., it has mass and velocity as much as the electron is a particle which has mass and velocity, and hence a linear momentum.

Photon Properties

A photon is a concentrated packet of energy which has mass, velocity and linear momentum. Its energy $E = h\nu$, it always moves at the speed of light c regardless of its frequency. Einstein showed that mass and energy were equivalent $E = mc^2$.A loss of mass

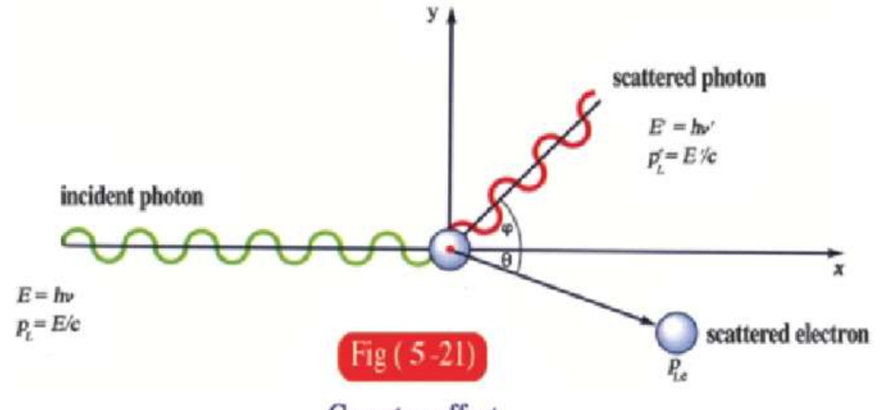


Fig (5-21)

Compton effect

is translated to released energy as in the atomic bomb (Fig 5-22). Nuclear fission is associated with a small loss of mass which is converted to large amount of energy due to the c^2(c^2 = 9 x 10^{16} m^2/s^2) factor. Therefore, the law of conservation of mass and the law of the conservation of energy blend into the law of conservation of mass and energy. Thus, a photon whose energy is hν has a mass of $h\nu/c^2$, while in motion . Since it is moving at velocity c, its momentum which is the product of mass and velocity becomes hν/c . If a beam of

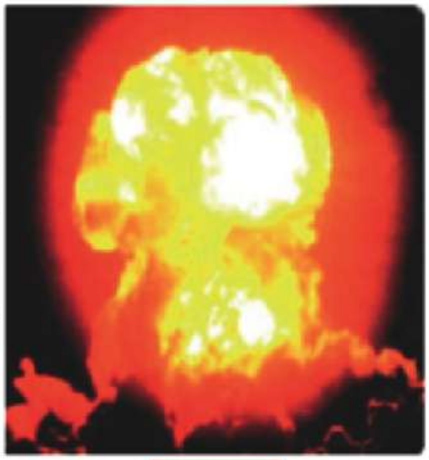


Fig (5-22)
Atomic bomb

photons is incident on a certain surface at the rate of ϕ_L (photons/s,), then each photon impinges on the surface and bounces off, and hence, suffers a change in linear momentum 2mc. The force which a beam of photons applies to the surface is the change in linear momentum per second:

$$F = 2mc\phi_L$$

$$F = 2\left(\frac{h\nu}{c}\right)\phi_L = \frac{2P_w}{c} \qquad (5\text{-}2)$$

where P_W is the power in watts of the light incident on the surface. This force is too small to be noticed. But it is appreciable if it affects a free electron instead, due to its small mass and size, so it throws it off. This is the explanation of Compton effect. In the microscopic model, we can image a phaton as a sphere whose radius is roughly equal to λ and oscillates at frequency ν. The stream of photons collectively has a magnetic field and an electric field. These two fields are perpendicular to one another and to the direction of propagation.Both oscillate at ν. The photon flux (or stream) carries the energy of the wave. The wave properties are ,thus, manifested by the photon stream as a whole. The wave

intensity measured by the magnitude of the electric or magnetic field associated with the light wave indicates the concentration of photons. Thus, the wave motion accompanies the photon stream. This is the macroscopic model. The microscopic and macroscopic models go hand in hand. But if we are working on the scale of the electron or atom, we must use the microscopic (photon) model. We conclude that the wave property and the particle property describe one and the same thing. But we must be aware when to use which. It all depends on the dimensions of the obstacle or the size that constricts light. If the obstacle is on the electron or atomic scale, i.e., within λ, we must use the photon model.

Example

Calculate the force applied by a beam of light whose power is 1W on the surface of a wall.

Solution

$$F = \frac{2\,P_W}{c} = \frac{2 \times 1}{3 \times 10^8} = 0.67 \times 10^{-8}\ N$$

This force is too diminutive to affect the wall

Relation between photon wavelength and its linear momentum

$$\lambda = c/\nu$$

Multiplying the numerator by h

$$\lambda = \frac{hc}{h\nu} = \frac{h}{h\nu/c} \qquad (5\text{-}3)$$

$$P_L = mc$$

$$= \frac{h\nu}{c^2}\,c$$

$$= \frac{h\nu}{c}$$

$$\therefore \boxed{\lambda = \frac{h}{P_L}}$$

Thus, the wavelength is Planck's constant divided by the linear momentum P_L. It should be noted that when photons fall on a surface, a comparison is made between λ and the interatomic distance of the surface. If λ is greater than the interatomic distance, these photons sense the surface as a continuous one and get reflected from it as in wave theory. If the interatomic distance is comparable to λ, photons penetrate through the atoms. This is what happens in the case of X- rays.

Example

Calculate the photon mass and linear momentum if $\lambda = 380$ nm

Solution

$$\nu = c/\lambda = \frac{(3\text{x}10^8 \text{ m/s})}{(380)\,(1\text{x}10^{-9}\text{m})}$$

$$= 7.89 \text{ x}10^{14} \text{ Hz}$$

$$m = E/c^2 = h\nu/c^2 = \frac{(6.625 \text{ x } 10^{-34} \text{ Js})\,(7.89\text{x}10^{14} \text{ s}^{-1})}{(3\text{x}10^8\text{m/s})^2}$$

$$= 5.81\text{x}10^{-36} \text{ kg}$$

$$P_L = h/\lambda = \frac{(6.625 \text{ x } 10^{-34} \text{ Js})}{(380)\,(1\text{x}10^{-9}\text{m})}$$

$$= 1.74 \text{ x}10^{-27} \text{ kgm/s}$$

Wave properties of a particle

In the universe, there is a great deal of symmetry. If waves have particle nature, could it be that particles might have wave properties ? a question posed by De Broglie in 1923 led to a hypothesis of wave particle duality applying to particles. The wavelength of a particle must be in analogy with a photon

$$\boxed{\lambda = h/P_L} \qquad (5\text{-}4)$$

where p_L is the linear momentum of the particle.

But what does this mean? We consider light as a huge stream of photons. Photons collectively have a wave property accompanying them, thus, manifesting reflection, refraction, interference and diffraction.The wave intensity describes the photon concentraction as if a photon carries the genes of light, regarding frequency, speed and wavelength. By the same token, an electron ray (e-beam) is a huge stream of electrons. Collectively, there must be a wave accompanying them. An electron carries the genes of the stream, regarding charge, spin and linear momentum. The accompanying wave has wavelength λ The intensity of the accompanying wave describes the electron concentration. Such a wave can disperse, reflect, refract, interfere and diffract, just as light does (Fig 5 -25). But does this mean we can use an electron ray as much as we use a light ray in a microscope? The answer is yes. This answer is verified by the discovery of the electron microscope.

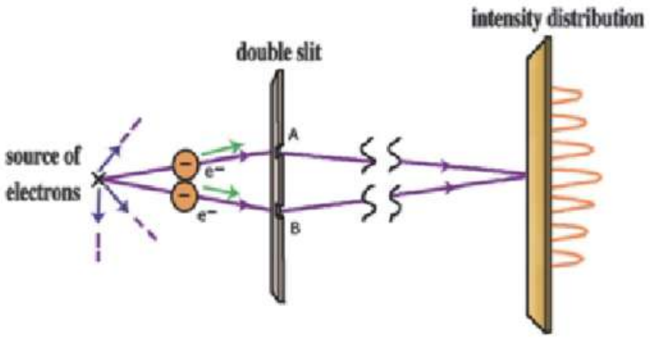
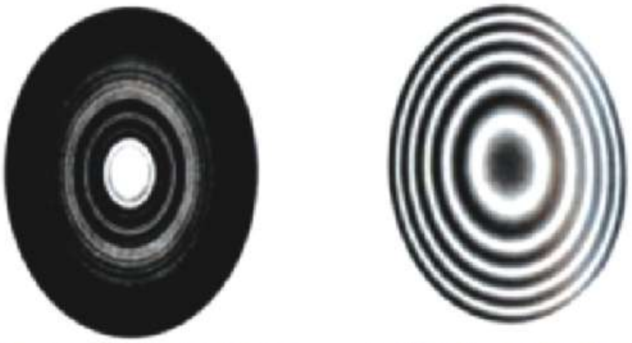


Fig (5 -25a)

Diffraction of electrons through a double slit



A diffraction pattern for electrons A diffraction pattern for light

Fig (5-25c)

Analogy between e-beam and and light

Electron Microscope

Electron microscope is an important lab instrument which depends in its operation on the wave nature of electrons. It resembles an optical microscope in many ways. The important difference is in the resolving power. The e-microscope has a high resolving power, because the electrons can carry a high kinetic energy, and hence very short λ (equation 5-4). Thus, its magnification is so high that it can detect very small objects, so small that an ordinary optical microscope fails to observe (Fig 5-26).

The optical microscope uses light, while the e-microscope uses an electron beam.
and the velocity of the free electron can be calculaated by the relation: $eV = 1/2\ mv^2$

The electron beam might have a wavelength 1000 times or more shorter than visible light.

Therefore, the electron-microscope can distinguish fine details. The lenses used in e-microscope are usually magnetic. These lenses focus the e-beam. Their design falls under the topic of electron optics.

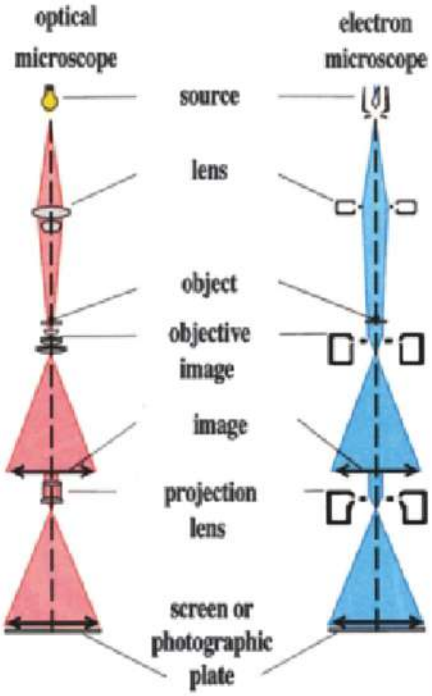


Fig (5 -26a)
Electron microscope

Fig (5-26b)
Head of a fly as seen by an e-microscope

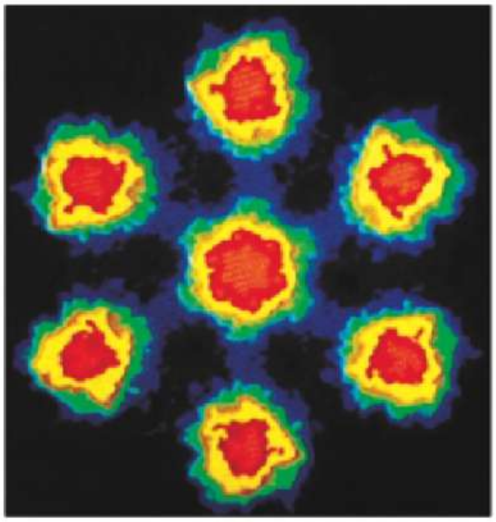


Fig (5-26c)
Uranium atoms as seen by a special type of e-microscopes

In a Nutshell

- Classical physics cannot explain many phenomena, particularly those in which light (or em radiation) interacts with electrons or atoms.
- Light or any em radiation consists of a huge collection of photons, each photon having energy hν, where h is Planck's constant and ν is the frequency.
- An evidence for photons is the photoelectric effect, where photocurrent depends on the intensity of incident light as long as the frequency is greater than a critical value ν_c. But if the frequency is less than ν_c, no photocurrent flows. The kinetic energy of the electron freed by the photoelectric effect depends on the frequency not on the light intensity.
- A photon has a mass, a linear momentum and a constant speed which is the speed of light. It has a size denoted by the wavelength. If a photon falls on a wall, it applies a small force on it, but if it falls on an electron, the electron will be thrown off due to its small mass and size.
- Compton effect proves the particle nature of photons, where a photon has mass, speed and linear momentum.
- A wave describes the collective behavior of photons.
- The wavelength of a photon is Planck's constant divided by the linear momentum. The same relation applies to a free particle, where the wavelength describes the wave nature of the particle ,i.e., the wave accompanying the particle.
- The electron microscope proves de Broglie relation for particles. It is used to detect diminutive particles.

Questions and Drills

I)Drills

1) Calculate the energy of a photon whose wavelength is 770 nm and find its mass and linear momentum?

($2.58x10^{-19}$J , $0.29x10^{-35}$kg , $0.86x10^{-27}$kgm/s)

2) Calculate the mass of an X- ray photon and a γ ray photon if the wavelength of X-ray is 100 nm , and that of γ-ray is 0.05 nm

(m_X=2.2 X10^{-35}kg , m_γ=4.4x10^{-32}kg)

3) Calculate the wavelength of a ball whose mass is 140 kg which moves at velocity 40 m/s. Also, calculate the wavelength of an electron if it has the same velocity.

(λ=1.18x10^{-37}m , λ_e=1.8 x10^{-5}m)

4) A radio station emits a wave whose frequency is 92.4 MHz. Calculate the energy of each photon emitted from this station. Also, calculate the rate of photons ϕ_L if the power of the station is 100 kW.

(E=612.15x10^{-28}J , ϕ_L=16.3 x10^{29} s^{-1})

5) An electron is under a potential difference 20 kV. Calculate its velocity upon collision with the anode from the law of conservation of energy. The electron charge is 16x10^{-19}C, its mass is 9.1 x 10^{-31} kg. Then calculate λ and P_L.

(v=0.838x10^{8}m/s , λ=0.868x10^{-11}m , P_L=7.625x10^{-23}kgm/s)

6) If the least distance detected with an electron microscope is 1nm, calculate the velocity of the electrons and the potential of the anode.

(velocity=0.725x10^{6}m/s , V=1.5Volt)

7) Calculate the force by which an e-beam whose power is 100 kW affects an object

whose mass is 10 kg , what happens if the object is an electron and why ?

$0.67 \times 10^{-3} N$

II) Essay questions

1) Show why the wave theory failed to explain the photoelectric effect, and how Einstein managed to interpret the experimental results of this phenomenon.
2) Show how to verify the particle nature of light from the blackbody radiation .
3) Explain the Compton effect and show how it proves the particle nature of light ?

Introduction to Modern Physics

UNIT 2

Chapter 6: Atomic Spectra

Overview

The word atom goes back to a Greek origin, meaning the indivisible. Different models for the atom have been put forth since then by many great scientists based on many experimental evidences.

Bohr's Model (1913)

Bohr

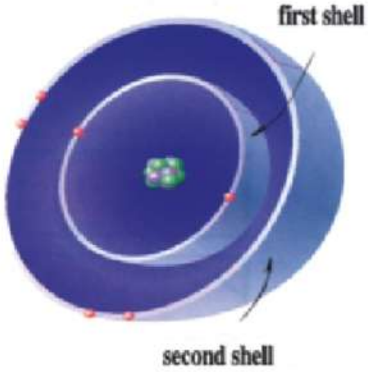


Fig (6-1a)
Bohr's Model

1) At the center of the atom there is a positively charged nucleus .
2) Negatively charged electrons move around the nucleus in shells. Each shell (loosely often called orbit) has an energy value. Electrons do not emit radiation as long as they remain in each shell (Fig 6 - 1).
3) The atom is electrically neutral, since the number of electrons around the nucleus equals the number of positive charges in the nucleus.

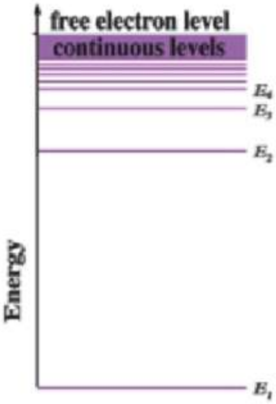


Fig (6-1b)
Energy levels

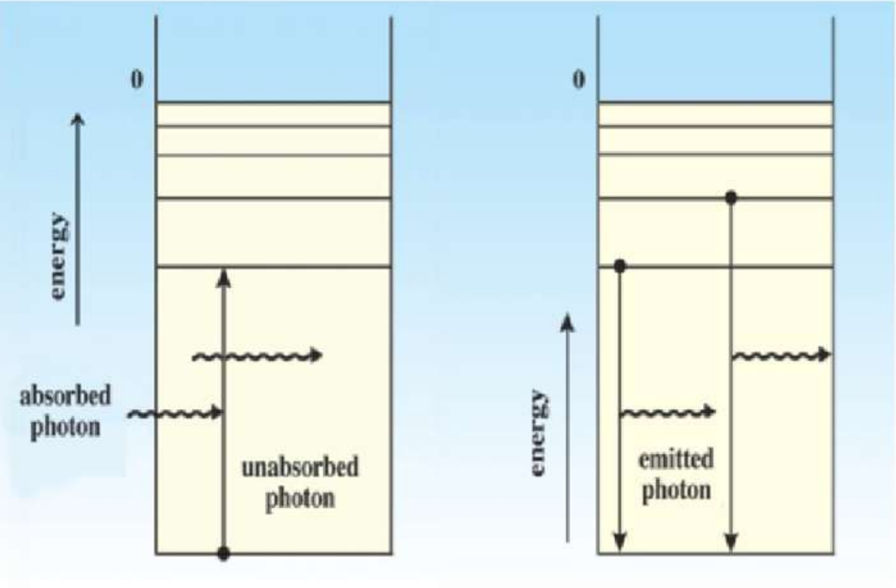


Fig (6-1c)
Absorption of photons

Fig (6-1d)
Emissin of photons

He then added three more postulates:

1) If an electron moves from an outer shell of energy E_2 to an inner shell of energy E_1 ($E_2 > E_1$), an amount of energy $E_2 - E_1$ is released in the form of a photon, whose energy $h\nu = E_2 - E_1$, where ν is the frequency of the emitted photon (Fig 6 - 2).

2) The electric (Coulomb's) forces and mechanical (Newton's) forces are at work in the atom.

3) We can estimate the radius of the shell by considering that the wave accompanying the electron forms a standing wave (calculate the shell radius for n = 1, 2, 3,)

The radius of the shell is given by :

$$n\lambda = 2\pi r_n \qquad \therefore r_n = \frac{n\lambda}{2\pi}$$

Emission of Light from Bohr's Atom.

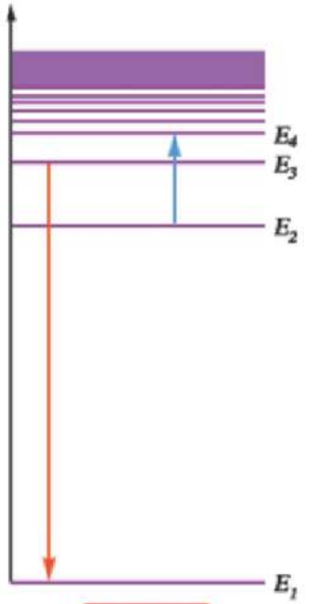
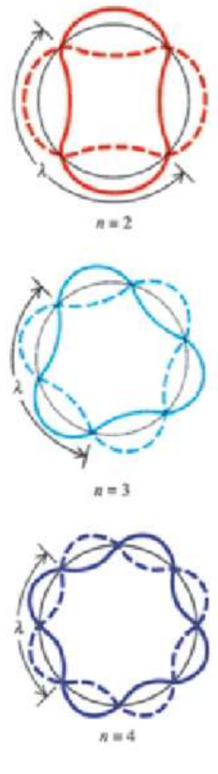


Fig (6 – 2)
Electron transitions between atomic levels



1) When hydrogen atoms are stimulated (given energy) not all of them are excited the same way. Thus, electrons in different atoms move from the first level K $(n = 1)$ to different higher levels $(n = 2, 3, 4..)$
2) Electrons remain in excited levels (or states) only for a short period of time ,called lifetime (nearly 10^{-8}s), then they revert to the lowest level (ground state).
3) In going down from level E_2 to level E_1, the electron emits a photon whose energy $h\nu = E_2 - E_1$: where ν is the frequency of the photon and its wavelength is : $\lambda = \frac{c}{\nu}$

The energy of a shell in the hydrogen atom can be given by the relation

$E_n = \frac{-13.6}{n^2}$ ev where $1 eV = 1.6\times10^{-19}$ Joule

4) The line spectrum of hydrogen consists of a particular energy value, and hence a particular frequency.

Different series of atomic spectral lines for hydrogen are produced, and are arranged as follows (Fig 6 - 3):

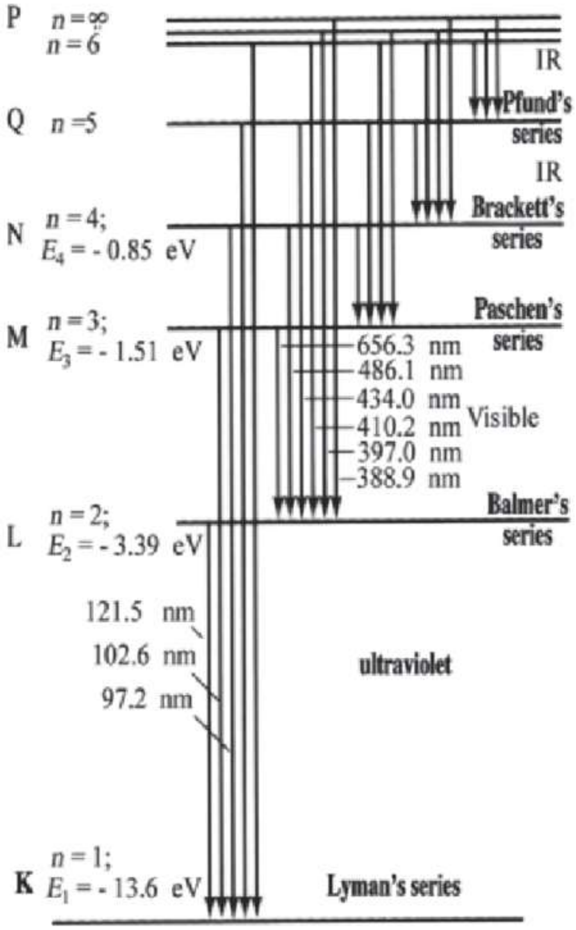


Fig (6-3a)

Atomic spectral series for hydrogen

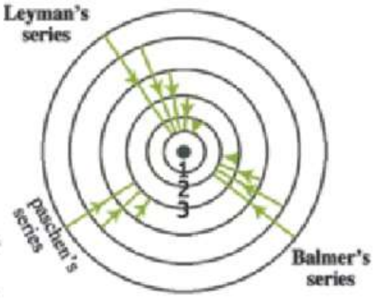


Fig (6-3b)

Atomic model for hydrogen spectrum spect

1) Leyman's series: where the electron moves down to level K (n = 1) from higher levels. This series lies in the ultraviolet range (short wavelengths and high frequencies).

2) Balmer's series: where the electron moves down to

level L (n = 2) from higher levels. This series lies in the visible range.

3) Paschen's series: where the electron moves down to level M (n = 3) from higher levels. This series lies in the infrared (IR) range.

4) Bracket's series: where the electron moves down to level N (n = 4) from higher levels. This series lies in the IR range.

5) Pfund's series: where the electron moves down to level O (n = 5) from higher levels. This series lies in the far IR and is the longest wavelengths (the lowest frequencies) among the line spectrum of hydrogen.

Spectrometer

To obtain a pure spectrum, a spectrometer is used (Fig 6 - 4). It consists of 3 parts :

1) a source of rays : a light source in front of which there is a slit whose width can be adjusted by a screw. This slit is at the focal point of a convex lens.

Fig (6-4a)
Spectrometer

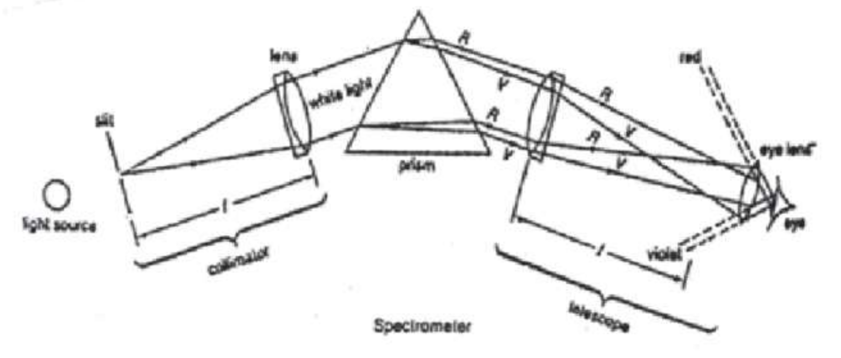


Fig (6-4b)
Spectrometer schematic

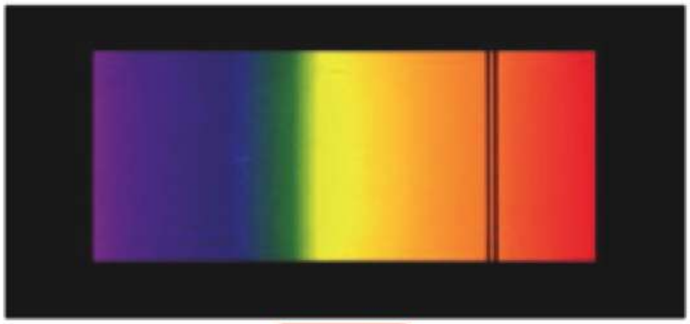


Fig (6-4c)
Use of a spectrometer to measure the temperature of the stars and their gases

2) a turntable on which a prism is placed.

3) a telescope consisting of two convex lenses (objective and eye piece).

Fraunhofer

To use the spectrometer for obtaining a pure spectrum, the slit is lit with bright light falling from the slit onto the prism at the minimum angle of deviation. The telescope is directed to receive the light passing through the telescope.The objective focuses the rays belonging to the same color at the focal plane of the lens . That is how we obtain a sharp (pure) spectrum.

From studying the line spectra of different elements whose atoms are excited , we notice different types of spectra (continuous and line) :

- the spectrum consisting of all wavelengths in a continuous manner is called the continuous spectrum.
- the spectrum occurring at specified frequencies and not continuously distributed is called the line spectrum.

Alternatively, they may be divided as emission and absorption spectra :

- the spectrum resulting from the transfer of excited atoms from a high level to lower level

is called the emission spectrum.

- It was found experimentally that when white light passes through a certain gas, some wavelengths in the continuous spectrum are missing. These wavelengths are the same as those which appear in the emission spectrum of the gas (Fig 6 - 4). This type of spectrum is called the absorption spectrum. Fraunhofer lines in the solar spectrum are examples of the absorption spectrum of the elements in the Sun, basically helium and hydrogen.

Fig (6 - 5)

Emission line spectra for some elements

X-rays

What are X-rays ?

They are invisible electromagnetic waves of short wavelength ($10^{-13} - 10^{-8}$m) between uv and gamma rays. They were first discovered by Rontgen. He called it so (the unknown rays) because he did not know what they were .

Properties of X-rays:

- They can penetrate media easily .
- They can ionize gases .
- They diffract in crystals .
- They affect sensitive photographic plates .

target

Coolidge Tube

This is used to produce X-rays. When the filament is heated, electrons are produced and directed at the target under the influence of the electric field,which gives them high energy, depending on the voltage difference between the target and the hot filament. When an electron collides with the tungsten target, part- if not all- of its energy is converted to X-rays (Fig 6 - 6).

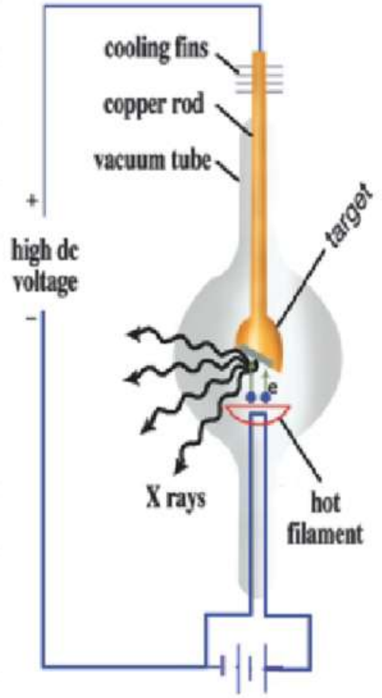


Fig (6- 6)
Coolidge tube

Spectrum of X-rays

Analyzing a beam of X-rays generated from a target to components of different wavelengths, we find that the spectrum consists of two parts :

a) the continuous spectrum of all wavelengths (within a certain range) regardless of the target material.

b) the line spectrum corresponding to certain wavelengths characteristic of the target material, called the characteristic X-ray radiation.

Interpretation of X-ray generation

a) characteristic radiation

The line spectrum is generated when an electron collides with an electron close to the nucleus of the target material atom. If the latter electron receives sufficient energy, it jumps to a higher level, or leaves the atom altogether, and is replaced by another electron

from a higher level. The difference in energy appears as radiation with a definite wavelength. It is noted that :

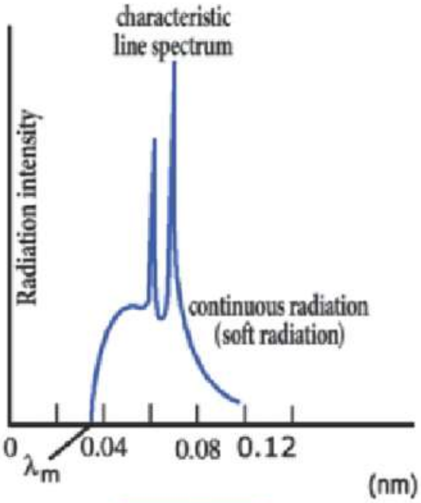


Fig (6-7)

Line and continuous spectra

1- the wavelength of the characteristic radiation does not depend on the voltage difference, but depends on the target element. The higher the atomic number of the target element, the shorter the wavelength of the characteristic radiation will be .

2- at low voltage differences, no characteristic radiation is produced.

3- the wavelength of the characteristic (often called hard) X-rays is found from the relation :

$$h \times \frac{c}{\lambda} = \Delta E \qquad (6\text{-}1)$$

b) Continuous Radiation

This radiation is generated when the velocity of the colliding electrons is reduced upon passing through a retarding electric field due to the electrons of the target material. This energy decrease is due to repulsion, collision, and scattering. Hence, an electromagnetic radiation is generated based on Maxwell – Hertz theory. This radiation is continuous and is called soft (bremsstrahlung,i.e.,braking radiation),i.e., the passing electron keeps losing

energy continually due to the braking effect of the surrounding electrons, giving rise to electromagnetic radiation covering all different possible wavelengths, since the electron loses energy gradually. This is the origin of the continuous radiation of X-rays.

Important Applications of X-rays

1) One of the important features of X-rays is diffraction, as they penetrate materials. That is why X-rays are used in studying the crystalline structure of materials (Fig 6 - 8). The atoms in the crystal act as a diffraction grating (which is a generalization of diffraction from a double slit). Bright and dark fringes form, depending on the difference in the optical path.

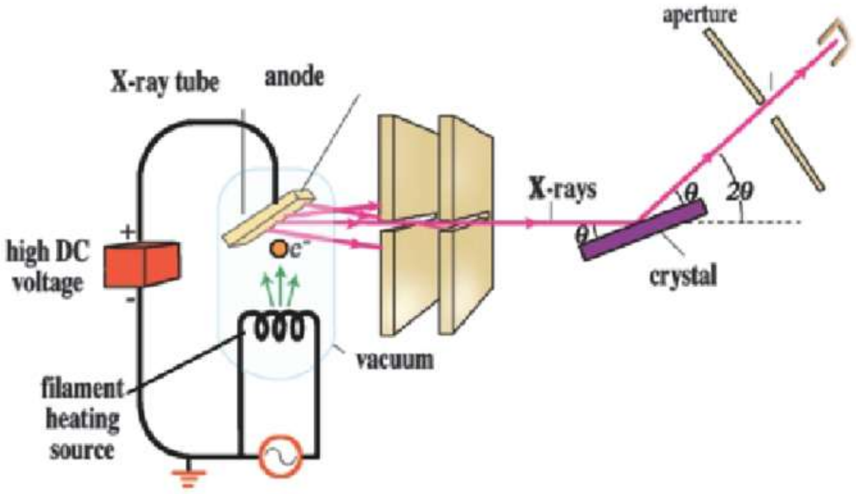


Fig (6- 8)
Use of X-rays in studying crystals

2) X- rays have a great penetrating power.

This is why they are used to detect defects in metallic structures.

3) X- rays are used in imaging bones and fractures and some other medical diagnosis (Fig 6 - 9).

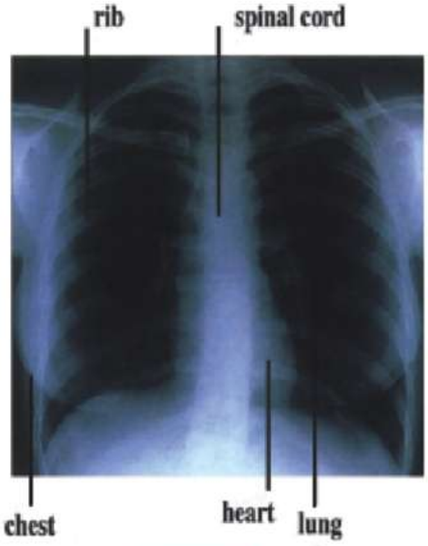


Fig (6- 9)

An X-ray image for the chest

In a Nutshell

- Bohr's postulates and model of the hydrogen atom :

When an electron jumps from a high level to a lower level, it produces radiation in the form of a photon of frequency ν and energy $h\nu$, which is equal to the difference between the two levels

$$h\nu = E_2 - E_1,\ E_2 > E_1$$

- The line spectrum of hydrogen consists of 5 series. Each line corresponds to a definite energy difference, frequency and wavelength

Lyman	uv
Balmer	visible
Paschen	IR (infrared)
Brackett	IR
Pfund	far IR

- The spectrometer is an apparatus used to decompose light to its components (visible and invisible)
- X-rays are an invisible radiation of short wavelengths, first discovered by Rontgen (1895).He called them the unknown (X) rays
- X-ray diffraction is used in studying the crystalline structure, and also in the industrial and medical applications.

Questions and Drills

I) Essay question:

1- How could Bohr explain the spectrum of the hydrogen atom ?

2- What is the basis on which the hydrogen spectrum is classified into five series ?

3- Explain why Leyman's series has higher energies than Pfund's.

4- Explain how a spectrometer is used to obtian a sharp (pure) spectrum.

5- Explain how X-rays are generated in coolidge tube.

6- Make a comparison between continuos and characteristic X-rays.

7- Explain the mechanism for producing each of the characteristic line spectrum and the continuos spectrum for X-rays then make a comparison between them ?

8- Discuss some applications of X-rays.

II) Define.

1- the line spectrum.

2- the continuos spectrum.

3- the absorption spectrum.

4- the emission spectrum.

Introduction to Modern Physics

UNIT 2

Chapter 7: Lasers

Chapter 7 Laser

Overview

Rarely has any discovery left an impact on applied science as the discovery of laser has done. Soon after its discovery, laser has been introduced into optics, biology, chemistry, medicine and engineering especially communications.

The word laser is an acronym for Light Amplification by Stimulated Emission of Radiation. In 1960, Maiman built the first laser out of chromium-doped Ruby. Later, He-Ne laser was manufactured along with other types of lasers.

Spontaneous Emission and Stimulated Emission

The atom has energy levels, the lowest of which is called ground state(E_1) in which the atom initially exists. The atom may be excited to one of higher states E_2, E_3 etc.

If we shine a photon with energy $h\nu = E_2 - E_1$ on the atom, the atom absorbs this photon and gets excited to E_2. Soon enough after a lifetime (nearly 10^{-8} s), the atom gets rid of this excitation energy in the form of a photon and goes back to its original state (Fig 7-1).

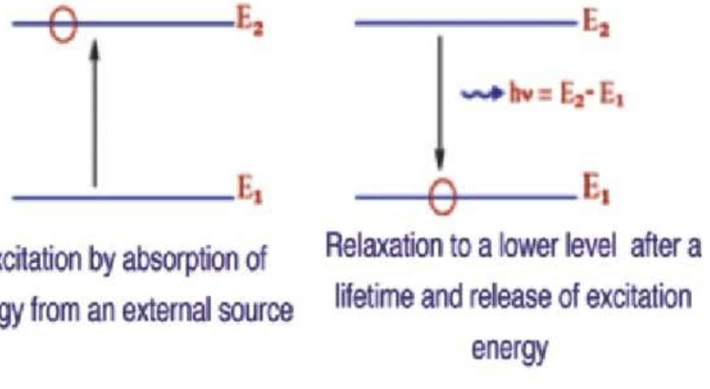


Fig (7-1)
Spontaneous emission

This type of radiation is called spontaneous radiation. It is the type of radiation common in ordinary light sources. The emitted photon has the same frequency and energy as the photon that caused the excitation . But the phase and direction are arbitrary. In 1917, Einstein showed that in addition to spontaneous radiation, there is another type of radiation, called stimulated emission (the dominant emission in lasers). If a photon of energy E_2-E_1 falls on an excited atom at level E_2 before the lifetime is over, this photon pushes the atom back to the ground state, and hence, the atom radiates the excitation energy in the form of a photon of the same frequency, phase and direction of the falling photon. (Fig 7–2).

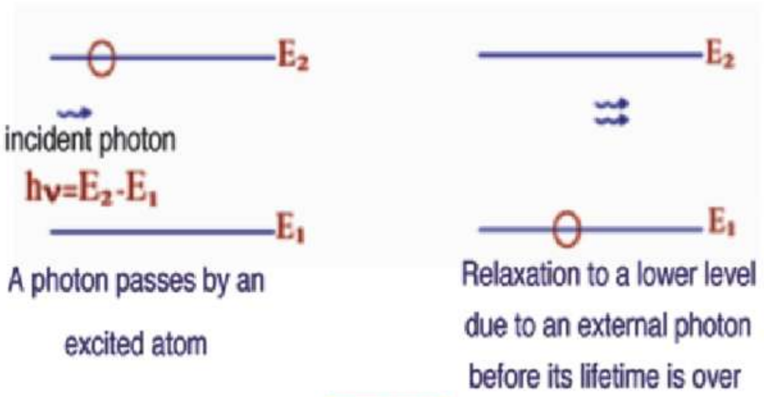


Fig (7-2)
Stimulated emission

Thus, throughout stimulated radiation, there are two types of photons; the stimulating and the stimulated photons moving together at the same frequency, phase and direction.

The emission of photons from the atoms of the material in this way renders these photons coherent and collimated for long distances. They are highly concentrated, and

remain unspread and unscattered, unlike photons emitted spontaneously.

The following table gives a comparison between spontaneous and stimulated emissions :

	Spontaneous emission	Stimulated emissions
1	- occurs when the atom relaxes from an excited state to a lower state, emitting spontaneously the energy difference in the form of a photon without the effect of an external photon. It occurs after the lifetime interval is over.	- occurs where an external photon stimulates excited atoms to emit the energy difference is the form of a photon before the lifetime interval is over.
2	- The emitted photons have a wide range of wavelengths.	- The emitted photons are monochromatic (single) wavelength.
3	- The emitted photons propagate randomly	- The emitted photons are coherent and propagate in one direction as a collimated parallel beam.
4	- The intensity of photons decreases according to the inverse square law. This is called spreading. While collisions with particles is called scattering. In ordinary light sources both spreading and scattering occur.	- The intensity remains constant over long distances contrary to the inverse square law. It has been possible to send a laser beam to the Moon and receive it back, without much loseses, despite the long distance involved. Spreading effect is nil and limited scattering takes place.
5	- This is the dominant radiation in ordinary light sources.	- This is the dominant radiation in laser sources.

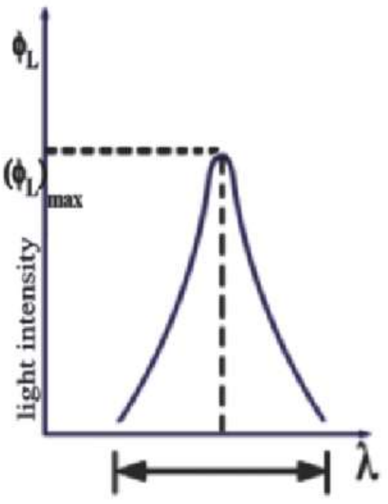


Fig (7-3a)
Spectral width for an ordinary monochromatic light source

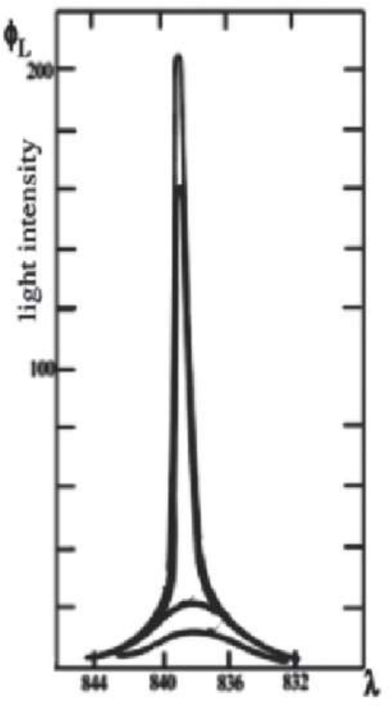


Fig (7-3b)
Spectral width for a laser source

Properties of a laser beam

1) **Monochromaticity:** Each line in the visible spectrum in ordinary light sources includes a band of wavelengths (this is why the ordinary color appears to have different shades to the naked eye). The intensity of each wavelength in this band width is shown in Fig (7–3a). A laser source emits one spectral line with a very limited bandwidth and the intensity is concentrated at the wavelength of that spectral line Fig (7–3b), hence it is called monochromatic.

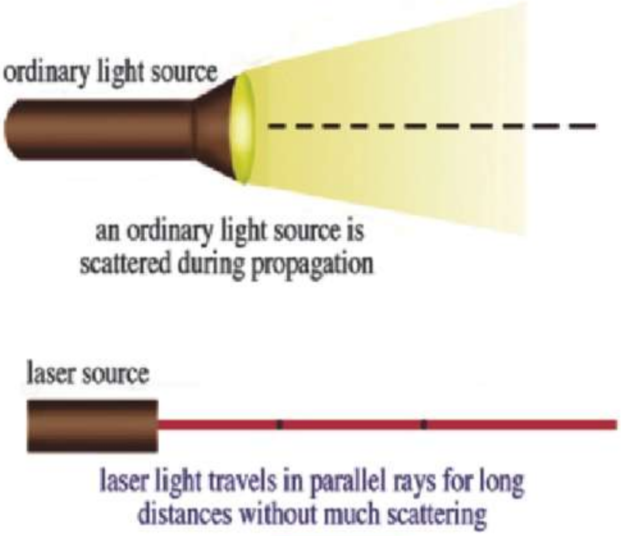


Fig (7 -4a)

Scattering of an ordinary light source and a laser

Fig (7 -4b)

Launching a laser beam from the Earth to a reflector on the surface of the Moon, 380000 km away

Fig (7-4c)
Measuring astronomical distances by a laser beam

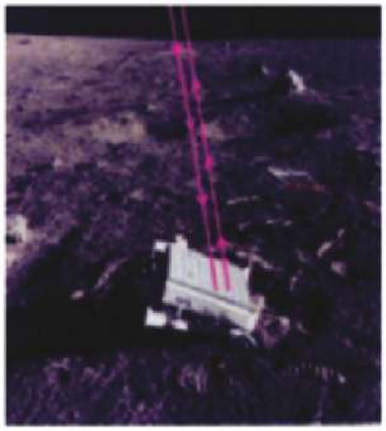


Fig (7-4d)
Measuring the distance between the Moon and the Earth by the reflection of a laser beam from a reflector on the lunar surface

2) **Collimation :** In ordinary light sources, the diameter of the emitted light beam increases with distance , where in lasers, the diameter stays constant for long distances without much unscattering. Thus ,energy is transmitted without much losses .

3) **Coherence:** Photons of ordinary light sources propagate randomly or incoherently. They emanate at different instants of time, and have inconsistent and varying phase. In lasers, however, photons emanate coherently both in time and place, since they come out together at the same time sequence, and maintains the same phase difference throughout, during propagation over long distances. This makes radiation intense and focused.

4) **Intensity:** Light produced by ordinary sources is subject to the inverse square law, since the intensity of radiation falling on unit area decreases, the further away from the light source, due to spreading (Fig 7-4a). The laser rays falling on a unit surface are unspread. They maintain a constant intensity and are not subject to the inverse squarelaw.

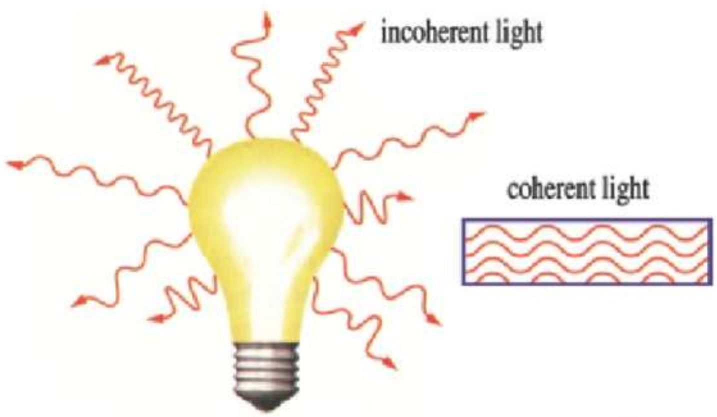


Fig (7-5)

Coherence

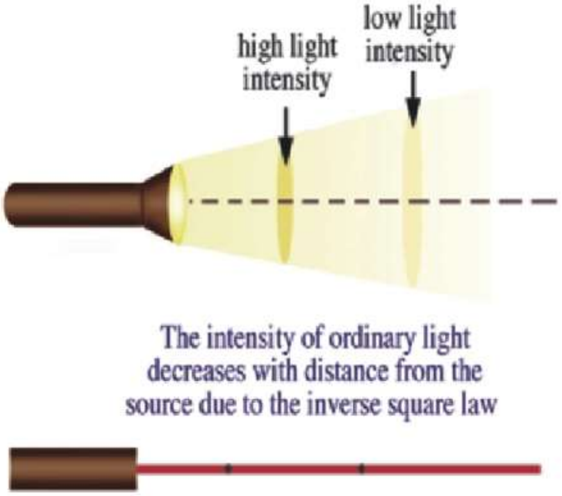


Fig (7-6)

Laser light maintains the same intensity as it propagates

Theory of the Laser Action:

Laser action depends on driving the atoms or molecules of the active medium into a state of population inversion, while maintaining a form of dynamic equilibrium. In this state, the number of atoms in the excited state exceeds the number of atoms in the lower

state. Thus, when stimulated emission occurs, it will be amplified as photons are increased in number going back and forth in the active medium, due to multiple reflections between two enclosing mirrors. In so doing, more and more excited atoms are poised to generate stimulated emission, which is further amplified and so on. This is the origin of amplification of the laser (Fig 7–7), called laser action .

Main Components of a Laser

Despite the variations in size, type and frequency, three common elements must exist in any laser:

1) **Active medium:** This can be a crystalline solid (e.g. ruby), semiconductor (chapter15) a liquid dye, gas atoms (e.g. He – Ne laser), ionized gases (e.g. Argon laser), or molecular gases (e.g. CO_2 laser).

2) **Sources of energy responsible for exciting the active medium as follows :**

(a) excitation by electrical energy, either by using radio frequency (RF) waves or by using electric discharge under high DC voltage gas lasers:(HeNe – Ar – CO_2).

(b) excitation by optical energy, also known as optical pumping, which can be done either by flash lamps (e.g. in ruby laser) or using a laser beam as a source of energy (liquid dye laser).

(c) thermal excitation, by using the thermal effects resulting from the kinetic energy of gases to excite the active material (e.g. in He-Ne laser).

(d) excitation by chemical energy as chemical reactions between giving gases energy to stimulate atoms toward lasing (e.g. the reaction between hydrogen and fluorine or the reaction between Deuterium fluoride and CO_2) .

3) Resonant cavity is the container and the activating catalyst for amplification . It can be one of two types :

(a) external resonant cavity in the form of two parallel mirrors enclosing the active medium permitting multiple reflections leading to amplification as in gas lasers (Fig 7 – 7a).

b) internal resonant cavity where the ends of the active material are polished so as to act as mirrors as in ruby laser (Fig 7 – 7b). One of the two mirrors is semitransparent to allow some of the laser radiation to leak out (Fig 14 – 8).

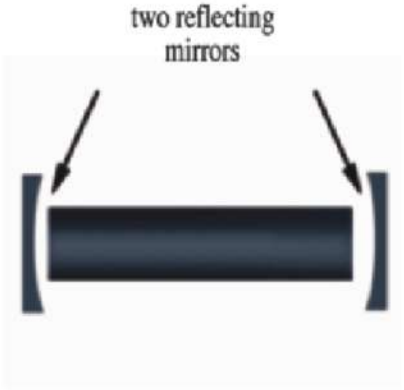


Fig (7-7a)
External resonant cavity

Fig (7-7b)
Internal resonant cavity

Unit 2: Modern Physics Chapter 7: Laser

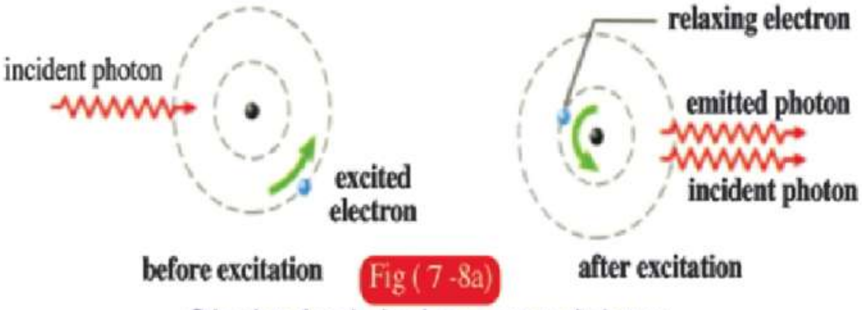


Fig (7 -8a)

Stimulated emission by an external photon

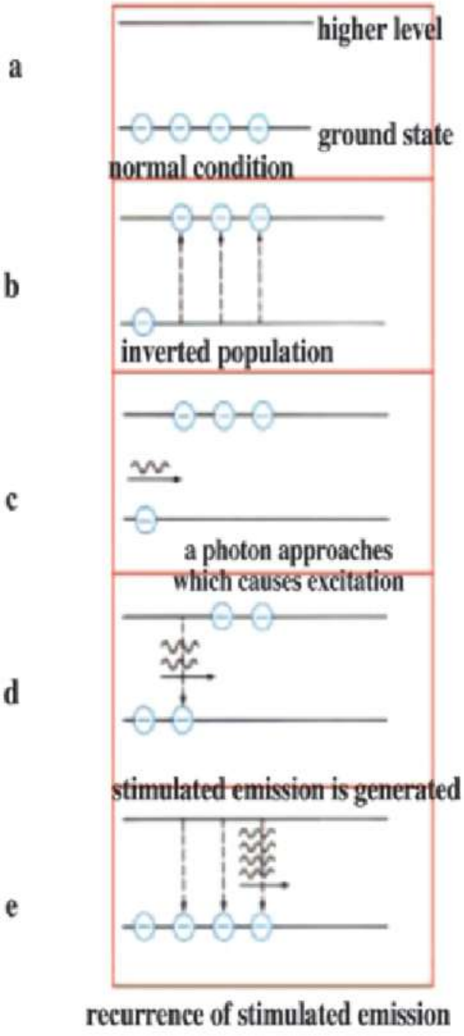


Fig (7 -8b)

Laser action

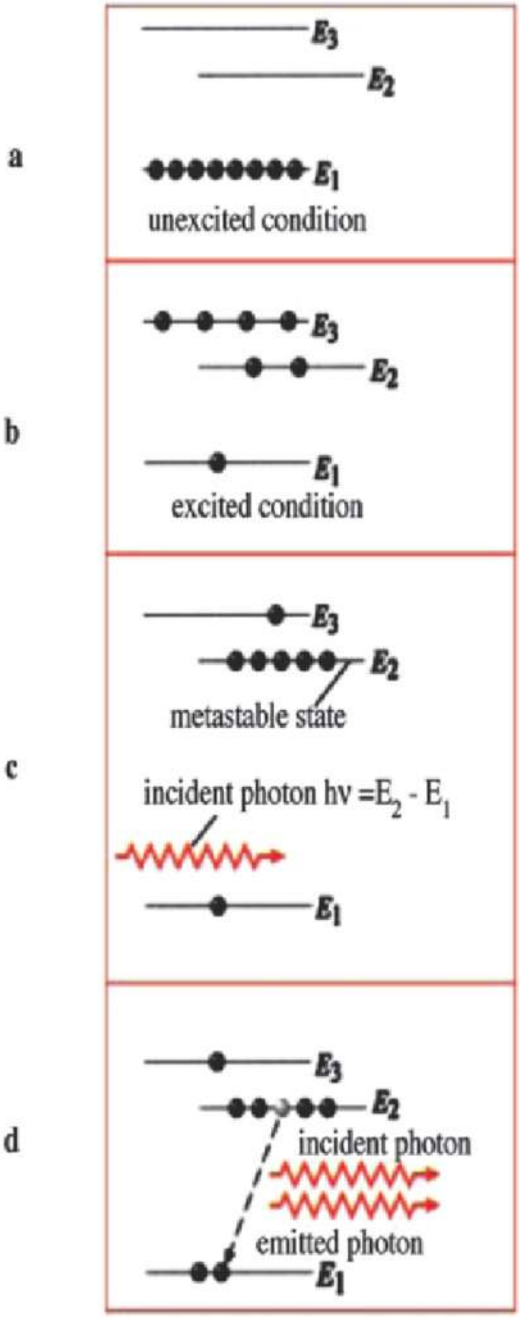


Fig (7-8c)

Population inversion through a third metastable state

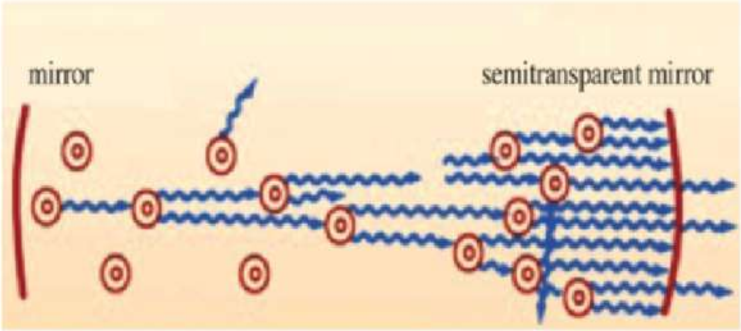


Fig (7-8d)
Multiple reflections between the two mirrors

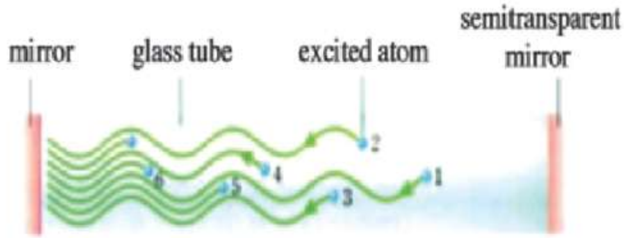


Fig (7-8e)
Amplification by multiple reflections

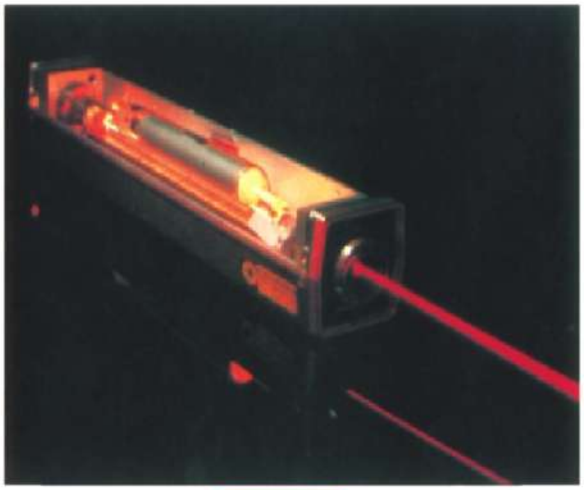


Fig (7-8f)
Output radiation from the semitransparent mirror

Helium – Neon (He – Ne) laser

These two elements have been selected due to the near equality of the values of the same metastable excited energy levels in these two elements.

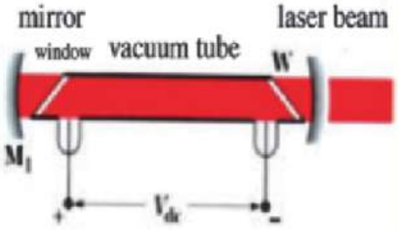


Fig (7 -9a)
He – Ne laser schematic

(a) Construction of He-Ne laser :

1) A quartz tube including a mixture of helium and neon in the ratio 10 : 1 at a low pressure of nearly 0.6 mm Hg (Fig 7 – 9).
2) At both ends of the tube there are two plane or concave parallel mirrors which are perpendicular to the tube axis. One has a reflection coefficient of nearly 99.5%, while the other mirror is semitransparent with a reflection coefficient of 98%.
3) High frequency electric field feeding the tube from the outside to excite the helium and neon atoms, or a high DC voltage difference inside the tube causing electric discharge.

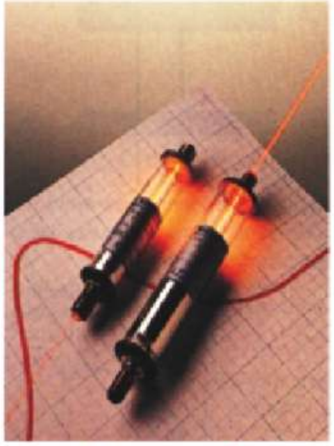


Fig (7 -9b)
He – Ne laser

(b) Operation :

1) The voltage difference inside the tube leads to the excitation of the helium atoms to higher levels (Fig 7 – 10).
2) The excited helium atoms collide with the unexcited neon atoms inelastic collisions. Thus, energy is transferred from the excited helium atoms to the neon atoms due to the near equality of the excited levels in both atoms. Neon atoms are, thus, excited.

3) An accumulation of excited neon atoms ensues. The excited level of a neon atom has a relatively long lifetime (nearly 10^{-3}s). Such a level is called metastable state. Hence, population inversion occurs in neon atoms.

4) A group of neon atoms that are excited relax to a lower excited state. In so doing, they emit spontaneous photons, which have energy equal to the difference in energy levels. Then, photons propagate randomly in all directions inside the tube.

5) Photons which propagate along the axis of the tube are reflected back by one of the two

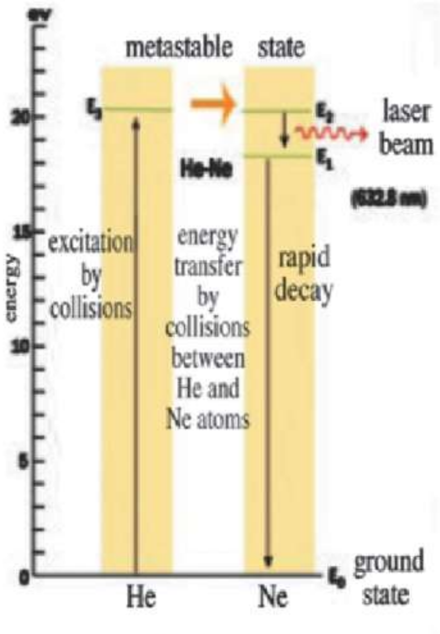


Fig (7-10a)

He – Ne laser energy levels

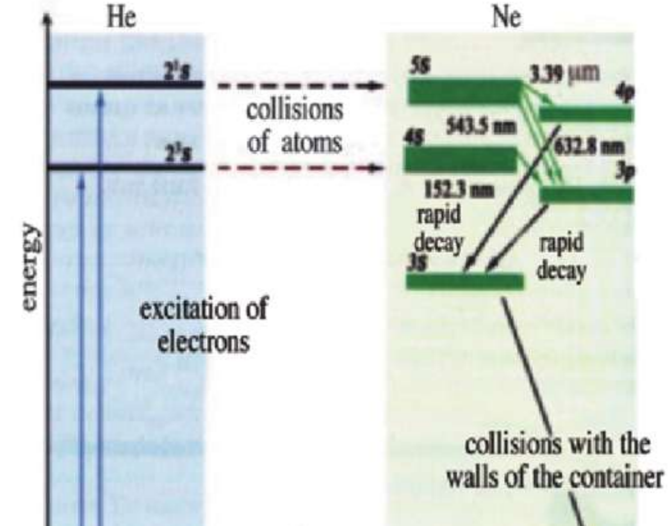


Fig (7-10b)

Transitions between energy levels in He-Ne laser

mirrors in its way, they bounce off inside the tube and cannot get out.

6) During the propagation of these photons inside the tube between the two mirrors, they may well collide with some neon atoms in the excited metastable state, well before lifetime is over. Thus, they stimulate the neon atoms to emit photons of the same energy and direction as the colliding photon. Thus, the number of photons moving inside the tube multiplies.

7) The new stream of photons repeat the excursion, and thus, they remultiply by the lasing action. This is how amplification takes place .

8) When radiation inside the tube reaches a certain level, we let it out partially through the semitransparent mirror, while the rest of the radiation remains trapped inside the tube. The stimulated emission and the lasing action go on.

9) As to the neon atoms which have relaxed to a lower level, soon enough they lose further whatever left of their energy in different forms, and finally go back to the ground state. Helium atoms collide again with neon atoms, and the cycle repeats.

10) As to the helium atoms which have lost their energy by collision, they regain energy through the electric discharge and so on.

Laser applications

Today there are different types and sizes of lasers. Laser light covers different regions of the electromagnetic spectrum from visible to uv and IR. Some laser systems can focus a laser beam in a small spot, where energy might get so high as to melt - and even evaporate - iron, or pierce diamond. There are lasers which may have enough energy to destroy missiles and planes in what is termed Star War. Some applications of lasers also include holography (Fig 7 - 11) and medical applications.

a) Holography:

Images of objects are formed by collecting rays reflected from them. An image represents variations in the intensity of light from point to point. But is light intensity all there is to it in the information about an image? If we have two rays leaving off an illuminated object at two points on it, there is a difference in intensity alright (proportional to the square of the amplitude of the wave). But in addition, there is a path difference between the two lit points and the corresponding points on the photographic plate where the image is recorded due to the topology of the object. Thus, the waves leaving off the object carry information in both amplitude and phase (phase difference = $\frac{2\pi}{\lambda}$ x path difference). The photographic plate records only the intensity (square of the amplitude) and does not record the phase. That is why a 2D image does not carry the 3D detail. In other words, a plane image has only half the truth (only the intensity). In 1948, a Hungarian scientist Gabor (Nobel prize laurette) proposed a method to obtain the component that is missing from the information in the image and retrieve it from the beam, using another beam of the same wavelength called the reference beam. A laser beam is split into two beams. One is used to illuminate the object, and the other is used as the reference beam. The reflected beam and the reference beam meet at the photographic plate, and interference takes place. After the photographic plate is developed, resulting interference fringes appear coded, and we call such an image a hologram. Illuminating a hologram with a laser of the same wavelength and looking through it with the naked eye, we see an identical 3D image of the object without using any lenses. The full information (intensity and phase) is now retrieved due to the coherence nature of the laser. Fig (7 – 12) shows the optical system used to obtain a hologram using a laser beam. Tens of photos may be stored in one hologram. We may also obtain 3D images in holograms of moving objects.

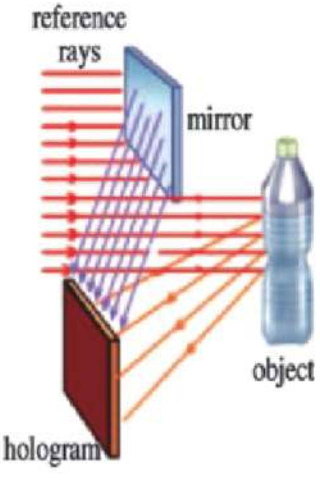


Fig (7 -12a)
Hologram formation

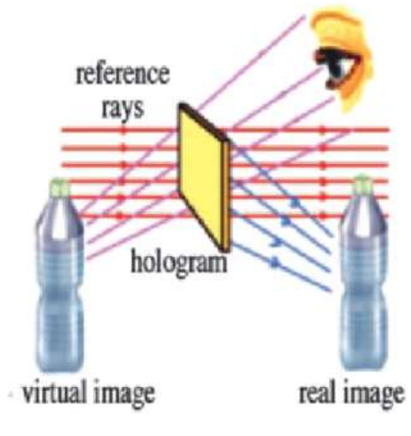


Fig (7-12b)
Hologram as a grating

b) Lasers in medicine:

The retina contains light sensitive cells. In case of retinal detachment, part of the retinal loses its function. Unless quickly treated, the eye may lose sight completely. In early stages, the eye may be treated by reconnecting the detached part with the layer underneath. This used to be a strenuous and delicate operation. Nowadays, lasers are used for that purpose Fig (7 – 14). The operation takes less time and efford than before. The thermal heat from the laser cauterizes the points of detachment (endothermy). Lasers are also used to treat cases of far and near sightedness, so the patient can dispose with glasses Fig (7-15). Other applications of lasers in medicine include endoscopy, where lasers with optical fibers are used for diagnosis and even operative surgery

Fig (7-14)
Use of a laser beam in treating retinal detachment

Other applications of laser

c) communications , where optical fibers carry information - loaded laser beam instead of a wire carring electrical signals.

d) industry, particularly fine industries.

e) military applications include precision guidance , smart bombs and laser radar (LADAR).

f) CD recording

g) laser printing where a laser beam is used to carry information from the computer to a drum coated by a photosensitive material. A toner is used to print off from the drum onto paper

h) arts and laser shows

i) surveying (determining dimensions and areas).

j) space research.

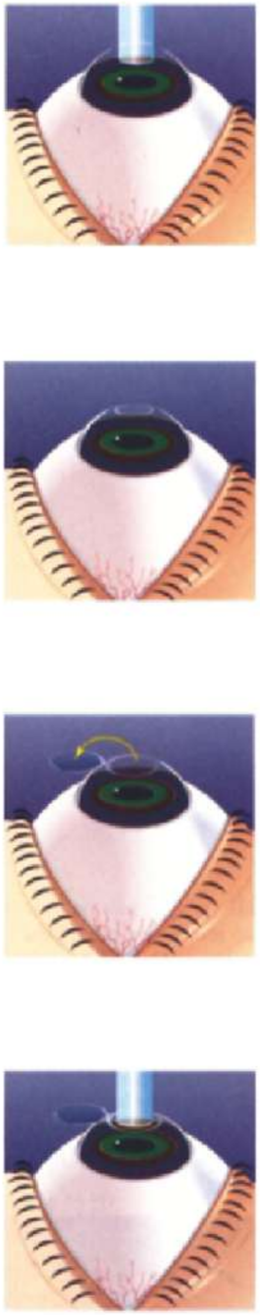


Fig (7 -15)
Cornea treatment by a laser

In a Nutshell

• Spontaneous emission:

It is the emission from one excited atom as it relaxes from a high energy level to a low energy level after its lifetime interval is over and under no external stimulus.

• Stimulated emission:

It is the emission from one excited atom as a result of a collision with an external photon, which has the same energy as the one that caused it to be excited. Photons at the end , come out in coherence ,i.e.,having the same phase, (direction and frequency).

• Properties of a laser beam :

1) spectral purity (monochromatic).

2) collimation (parallel rays).

3) coherence (same phase and direction).

4) concentration (high intensity and small diameter).

• Laser action :

1) the active medium must be in the state of population inversion .

2) emission of radiation for the excited atom through the stimulated emission.

3) amplification of stimulated emission through the resonant cavity

• Basic elements of a laser :

1) an active medium.

2) a source of energy (pumping).

3) a resonant cavity.

• He - Ne laser is a gas laser:

in which the active medium is a mixture of helium and neon in the ratio 10 : 1

- **Laser applications:**

1) 3D photography (holography).

2) medicine (e.g. treating retinal detachment).

3) communications.

4) industry.

5) military applications.

6) CD recording

7) printing

8) arts and shows

9) surveying

10) space research

Questions and Drills

1- What is meant by laser ?

2- Compare between spontaneous emission and stimulated emission operation - wise and feature - wise.

3- Laser light has special characteristics which distinguish it from ordinary light . Discuss this statement .

4- Discuss clearly the laser action .

5- What is meant by optical pumping and population inversion?

6- What is the role of the resonant cavity in laser operation ?

7- Lasers have 3 main components, what are they ?

8- On what basis have helium and neon been chosen as an active medium in He - Ne laser ?

9- What is the role of helium in He - Ne laser ?

10- Explain clearly how a laser beam is generated in He - Ne laser .

11- Explain how holography works using lasers .

12- Lasers are used extensively in medicine. Discuss one of its applications .

13- Lasers play an important role in missile guidance in modern warfare. Why is laser used as such?

Introduction to Modern Physics

UNIT 2

Chapter 8: Modern Electronics

Chapter 8 Modern Electronics

Overview:

The world witnesses a tremendous mushrooming in the field of electronics and communication to the point where they have become an insignia for this era. Electronics and communication are now indispensible in our life. TV, cellular (mobile) phone , computer, satellites and other systems are evidences for the vast progress in the applications of electronics and communications, whether in business, e-government, information technology(IT), entertainment or culture. They have become also an essential ingredient in modern warfare. Weapons do not fare from the point of view of fire power only, but guidance, surveillance, monitoring jamming and deception ,called electronic counter measures (or ECM) play an important role in combat. Also, in medicine whether in diagnois, prognosis, or operations, electronics plays a key role. In short, there is no single field in all walks of life where electronics has no part, starting from e –games to e– warfare. Therefore, you must attain a certain level of awareness about electronics – simplified as it may be, yet essential regardless of the prospective career you might end up with.

Pure Semiconductors:

There are three types of materials from the point of view of electrical conductivity. Conductors conduct electricity and heat easily (as in metals). Insulators do not conduct electricity and heat (as in wood and plastics). Semiconductors are in between. At absolute zero, they act as insulators, whereas as temperature increases ,their conductivity increases (as in silicon).

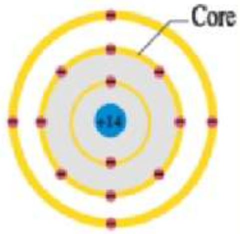


Fig (8-1)
A silicon atom

Silicon is one of the important and common elements in the universe. It exists in sand (SiO_2) and rocks of the Earth's crust. But crystals of pure silicon consist of silicon atoms bound together in covalent bonds. A crystal is a regular arrangement of atoms in the solid state. A silicon atom has four electrons in the outermost shell (Fig 8 – 1). Therefore, each silicon atom shares 4 electrons with 4 neighboring atoms, so that the outer shell of each is complete on sharing basis to contain 8 electrons each (Fig 8 – 2 a,b). We must distinguish here between two types of electrons in silicon. The first type is the innermost (tightly bound) electrons, which are strongly attracted to their parents atoms. The second type is the valence electrons, which have more freedom to move across interatomic distances. They exist in the outermost shell. At low temperatures (Fig 8 - 2c), all bonds in the crystal are intact (unbroken).

In this case – unlike metals – there are no free electrons. But as temperature increases,

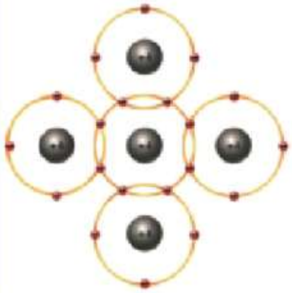


Fig (8-2a)

Each atom shares electrons with its neighbors

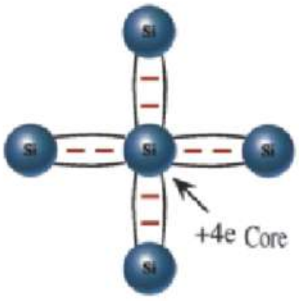


Fig (8 -2b)

Covalent bonds. We may represent a S_i atom (-14 e) around (+14 e) nucleus as a core (+4e) and (-4e) in the outer shell

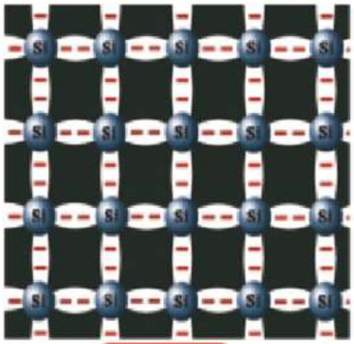


Fig (8 -2c)

Silicon crystal at T=0°K all bonds are intact

some bonds, are broken and electrons are freed. Such an electron leaves behind a vacancy in the broken bond.This vacancy is called a hole (Fig 8 – 3). Because the atom is neutral, then the absence of an electron entails the appearance of a positive charge. We, thus, say that the hole has a positive charge. We do not call a silicon atom which loses an electron from its bond an ion, because soon enough, this atom may capture a free electron or an electron from another bond to fill its own vacancy. Then, the atom returns neutral, and the

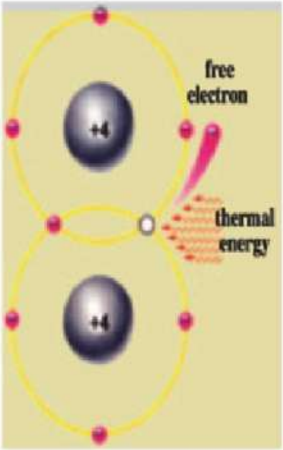


Fig (8-3a)

Breaking a bond requires energy

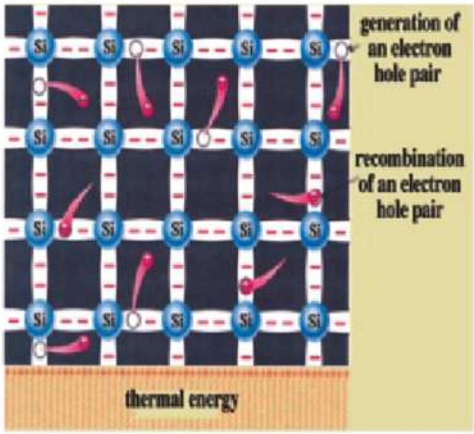


Fig (8 -3b)

As temperature increases more bonds are broken

broken bond is mended, and the hole shifts somewhere else, and so on.

As the temperature increases, the number of free electrons and holes increases, noting that the number of free electrons equals the number of free holes in a pure semiconductor. But a state of dynamic equilibrium is reached (called thermal equilibrium) at which only a small percentage of bonds are broken. The number of bonds broken per second will be equal to the number of bonds mended per second, so that a fixed number of free electrons and free holes remains constant at every temperature. But not the same electrons and same holes remain free.They reshuffle ,but their number stays constant.

Free electrons (a class of valance electrons) represent a third type of electrons in silicon. Such electrons in fact are still confined, but they are confined to the full size of the crystal itself, i.e., are limited by the so called surface of the crystal. Breaking a bond requires a minimum energy (thermal or optical). In the case of mending a bond (called recombination), energy is released (thermal or optical).

As the electrons move in a random motion ,so do the holes, since electrons in the bond move around randomly to fill in vacancies (voids) within the broken bonds (Fig 8 – 4).

Fig (8-4a)

Holes move randomly between bonds

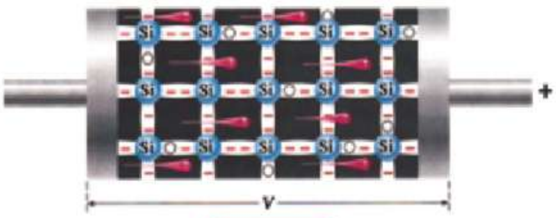


Fig (8-4b)

Motion of holes is equivalent to motion of electrons within bonds (in the opposite direction)

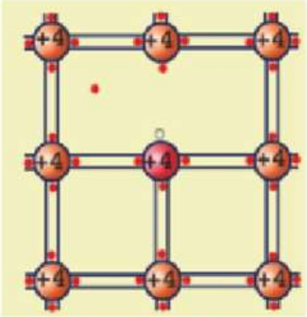


Fig (8-4c)

At a certain temperature, the number of free electrons and holes is constant

Doping:

Semiconductors are known to be sensitive to impurities and to temperature. Since silicon is tetravalent, the addition of an element as phosphorus (P) or antimony (Sb) or any other pentavalent element will cause such an impurity atom to replace a silicon atom in the crystal (Fig 8 – 5 a). Then, the phosphorus atom will try to do the same bonding with the neighbors as the silicon atom would do.

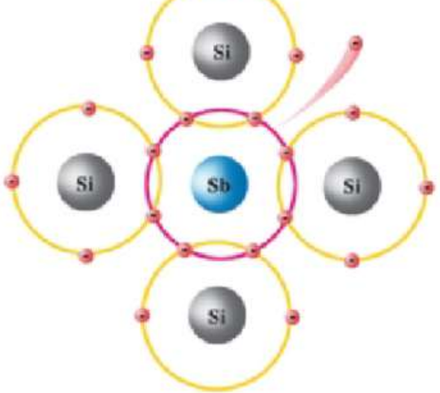
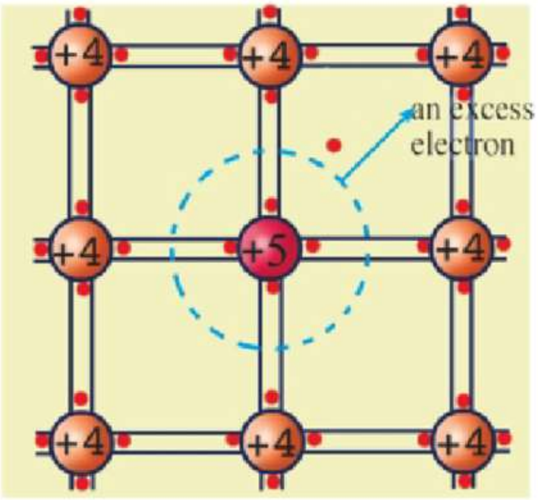


Fig (8-5a)

An antimony atom (pentavalent) replaces a silicon atom

Because the impurity atom has 5 electrons, four of them will take part in the bonding scheme, sparing one valence extra (excess) electron. The force of attraction on the excess electron which is left out is weak. Hence, it can easily be detached from its parent atom, which becomes a positive ion.This extra electron joins the stock of the free electrons in the crystal . In other words, the crystal has an added source of free electrons besides broken bonds, namely, impurity atoms. Such impurity atoms are called donors (givers). At thermal equilibrium, the sum of the positive charge equals the sum of the negative charge.

$$\boxed{n = p + N_D^+} \qquad (8 - 1)$$



(Fig 8-5b)

Doping with a pentavalent atom provides an extra free electron. A pentavalent atom has a core (+5 e) and 5 electrons

where N_D^+ is the positive donor ion concentration, n is the free electron density and p is the hole density. In this case, n > p and the material is called n–type. Conversely, if we add aluminum (Al) or boron (B) or any trivalent element, to pure silicon, the impurity atom replaces a silicon atom. Since the impurity atom now has 3 electrons in the outershell, it detaches an electron from a neighboring bond to complete its own bond creating an extra hole, becoming a negative ion. At thermal equilibrium ,

$$p = N_A^- + n \qquad (8-2)$$

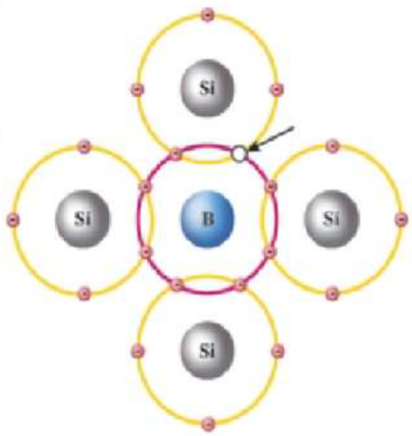


Fig (8-6a)

A boron atom replaces a silicon atom

where N_A^- is the negative impurity concentration. Thus, p>n. Such an atom is called acceptor (taker). In all cases, we have

$$np = n_i^2 \qquad (8-3)$$

where n_i is the electron or hole concentration in pure silicon, i.e., if n increases, p decreases and vice versa. This is called law of mass action. As an approximation, we may say :

in case of n-type

$$\boxed{n = N_D^+} \qquad (8 - 4)$$

$$\boxed{p = n_i^2/N_D^+} \qquad (8 - 5)$$

In case of p-type,

$$\boxed{p = N_A^-} \qquad (8 - 6)$$

$$\boxed{n = n_i^2/N_A^-} \qquad (8 - 7)$$

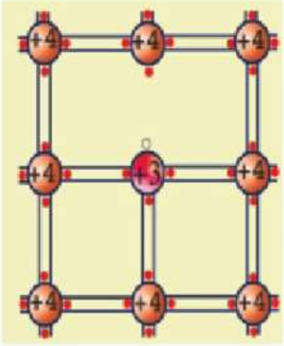


Fig (8 -6b)

Doping with a trivalent atom provides an extra hole. A trivalent atom has a core (+3e) and 3 electrons

Electronic Components and Devices

Electronic components and devices are the building blocks for all electronic systems (Fig 8 – 7). Some of these components are simple, e.g., resistor (R), inductor (L), capacitor (C). Some are more complex, such as pn junction (diode), transistor. There are also other specialized devices, such as optoelectronic and control devices. Semiconductors from which most of these devices are made are known to be sensitive to environmental conditions, such as light, heat, pressure, radiation and chemical pollution. That is why they are used as sensors or means for measuring external stimulii. Using these sensors, we can measure the intensity of incident light, temperature, pressure, humidity, pollution, radiation,etc.

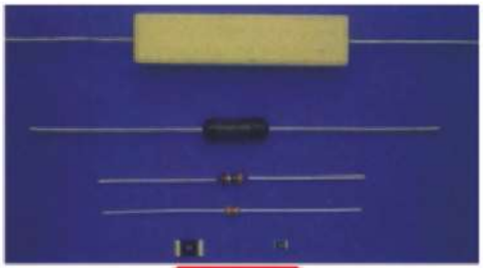


Fig (8 -7a)
Resistors

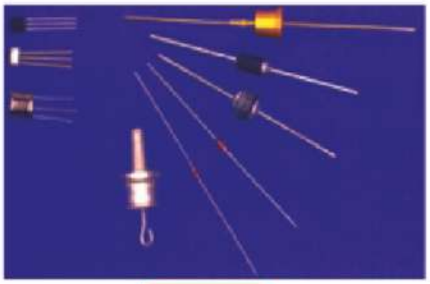


Fig (8 -7b)
Diodes and transistors

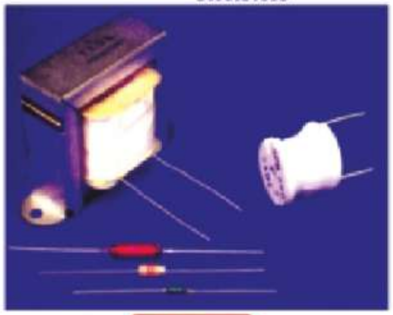


Fig (8 -7c)
Inductors

Fig (8 -7d)
Capacitors

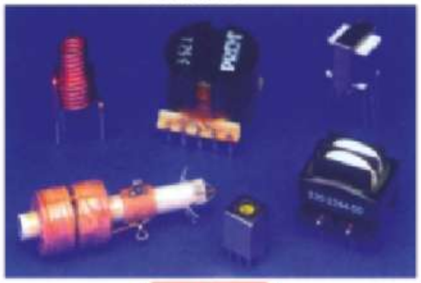


Fig (8 -7e)
Transformers

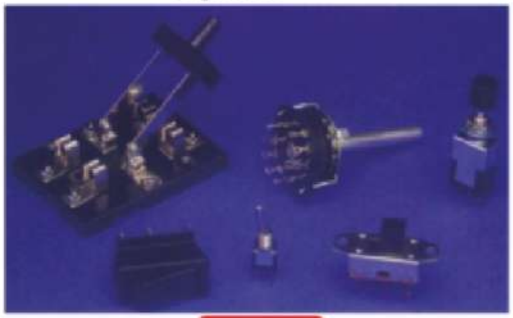


Fig (8 -7f)
Switches

Fig (8 -7g)
A different set of components and devices
(Can you recognize some?)

pn junction:

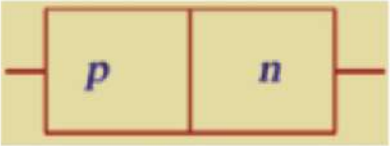


Fig (8-8)
A pn Junction

A pn junction (Fig 8 – 8) consists of an n–type region and a p-type region. The name pn stands for p-region and n-region not positive and negative. Also p,n regions are not two regions glued together but an n-material is converted in part to p-material or vice versa. Holes in the p–type region have high concentration, while holes in the n–type region have low concentration. Therefore, some holes diffuse from the p-type region to the n–type region. Also, some electrons diffuse from the n–type region (high concentration for electrons) to the p–type region (low concentration for electrons). Since each region is neutral (the sum of positive charge equals the sum of negative charge), the transfer of some electrons from the n–type region uncovers an equal number of positive donor ions, and the transfer of some holes from the p–type region uncovers an equal number of negative acceptor ions. This results in a middle region composed of positive ions on one side, and negative ions on the other, while no electrons or holes exist in this region. This region is called transition (depletion) region. In such a region, an electric field is set up, directed from the positive ions to the negative ions. This electric field causes a drift current to flow in a direction opposite to the diffusion current. At equilibrium, the forward current is balanced with a reverse current, so that the net current is zero (Fig 8 – 9). If we apply an external voltage such that the p-type region is connected to the positive terminal of the battery

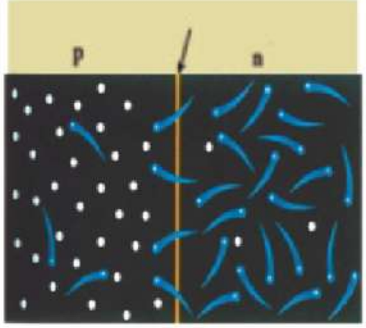


Fig (8-9a)
Electrons diffuse from n to p and holes from p to n

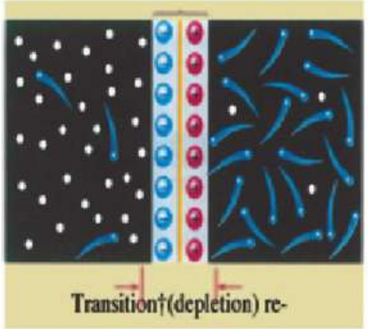


Fig (8-9b)
Transition region depleted from electrons and holes, only ions exist

and the n-type region to the negative terminal of the battery, the field due to the battery is opposite to the internal field.in the transition region, and therefore, it weakens it. If we reverse the battery, then the two fields will aid each other. In the first case (forward bias), a net current will flow, and in the second case (reverse bias) current is almost zero (Fig 8-12). The action of the pn junction is like a switch, which is closed in the forward direction (conducting) and open (non conducting) in the reverse direction (Fig 8-13). We can make sure that the pn diode is functioning by using an ohmmeter, since the diode should have a small resistance in the forward direction and a large resistance in the reverse

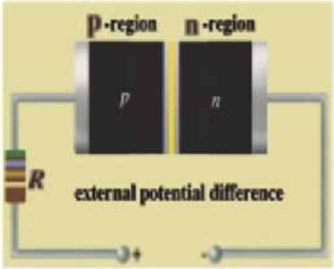


Fig (8-10a)
Forward Bios

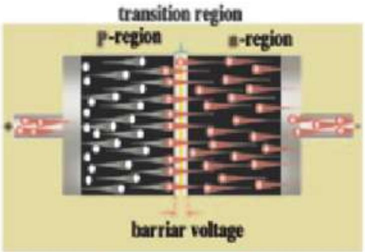


Fig (8-10b)
Motion of electrons and holes due to forward bias

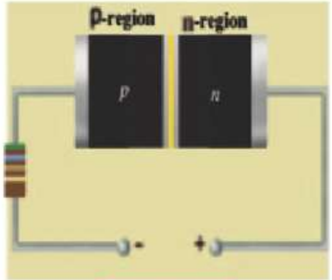


Fig (8-11a)
Diode in reverse bias

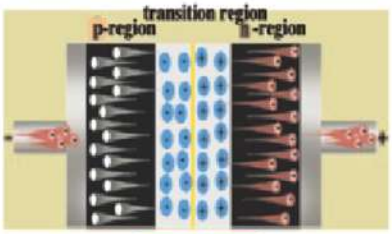


Fig (8-11b)
Motion of electrons and holes due to reverse bias

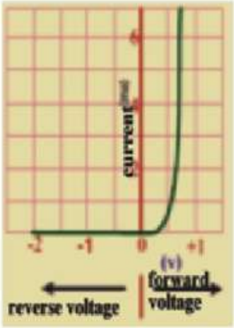


Fig (8-12)
I - V characteristic in a pn diode

Fig (8-13a)
Diode symbol

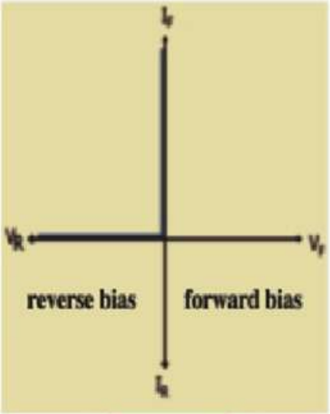


Fig (8-13b)
Ideal I-V characteristic

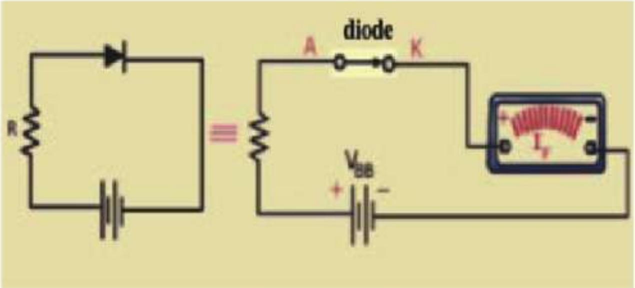


Fig (8-13c)
In forward bias the diode is like a closed switch

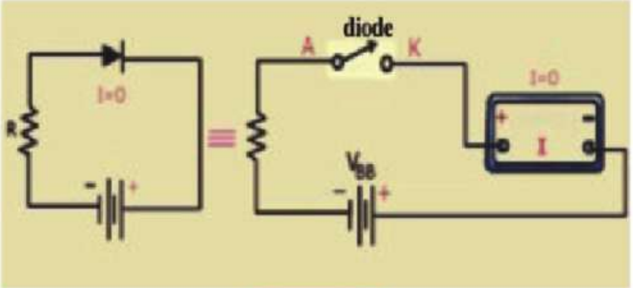


Fig (8-13d)
In reverse bias the diode is like an open switch

Learn at Leisure

Electronic tuning

To tune up a TV or radio onto a certain station, we need to adjust the value of a capacitor to set the frequency of the receiver to the frequency of the selected broadcast station. This condition is called resonance. In modern receivers, the capacitor is replaced by a reverse biased pn diode . The width of the transition region increases with increasing reverse bias (Fig 8 - 15). The increase of the width of the transition region entails an increase of the fixed ionic charge on both sides of the transition region with reverse voltage. This is tantamount to capacitor action. Thus, we can change the value of the capacitor by controlling the revese voltage. This is called electronic tuning (and the device is called a varactor).

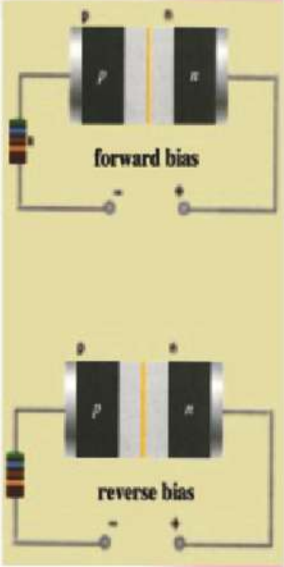


Fig (8-15)

The width of the transition region increases with increasing reverse bias

Transistor:

The transistor was cenceived in 1955 by Bardeen, Schockley and Brattain. There are many types of transistors, but we focus here on bipolar junction transistor (BJT), i.e., pnp or npn. Such a transistor consists of a p-region followed by an n-region then a p-region (pnp), or an n-region followed by a p-region then an n-region (npn) (Fig 15- 16). The three regions are called emitter (E) -base (B) and collector (C). Consider an npn transistor. The first junction (np) is forward biased. The second (pn) junction is reverse biased. In this case, electrons are emitted from the

Bardeen, Schochley and Brattain

negative emitter (n) diffusing to the base (p), where they wander around in the base until picked up by the positive collector (n).A portion of electrons gets recombined with holes. If the emitted electorn current is I_E and the portion that reaches the collector I_c is $I_c = \alpha_e I_E$, then the protion lost in the base by recombination with holes is $I_B = (1-\alpha_e)I_E$. This must be the base current supplying holes to the base to make up for the losses due to the recombination process. Therefore, the ratio of the collector current to the base current is:

$$\beta_e = \frac{I_C}{I_B} = \frac{\alpha_e I_E}{(1-\alpha_e)I_E} = \frac{\alpha_e}{1-\alpha_e} \qquad (8-8)$$

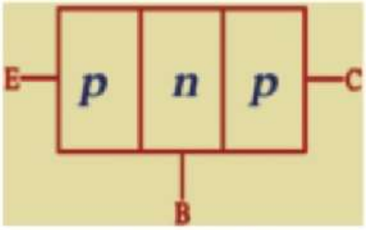


Fig (8-16a)
A pnp transistor

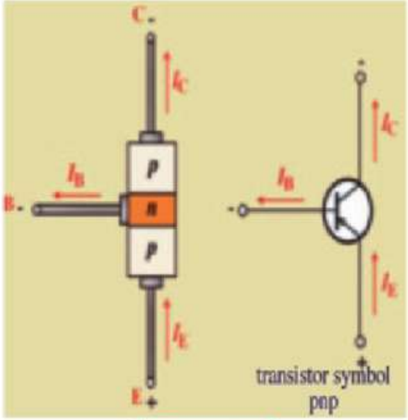


Fig (8-16b)
A pnp transistor

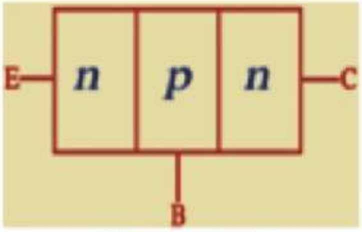


Fig (8-16c)
An npn transistor

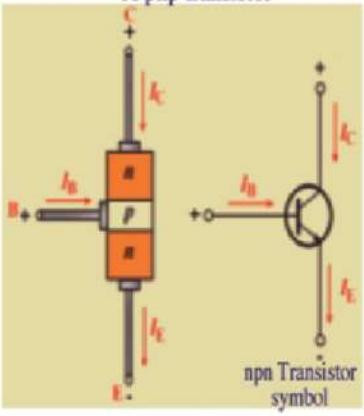


Fig (8-16d)
An npn transistor

Because the base width is very small, α_e is very close to unity (only a very small portion is lost to recombination).

Thus, β_e is very large, and the collector current I_C is larger than the base current I_B.

The ratio β_e is called the current gain. Thus, if the base current is a small electrical signal, its effect appears amplified in the collector current. This is the basic idea of the transistor action, i.e., the transistor acting as an amplifier (Fig 8-17).

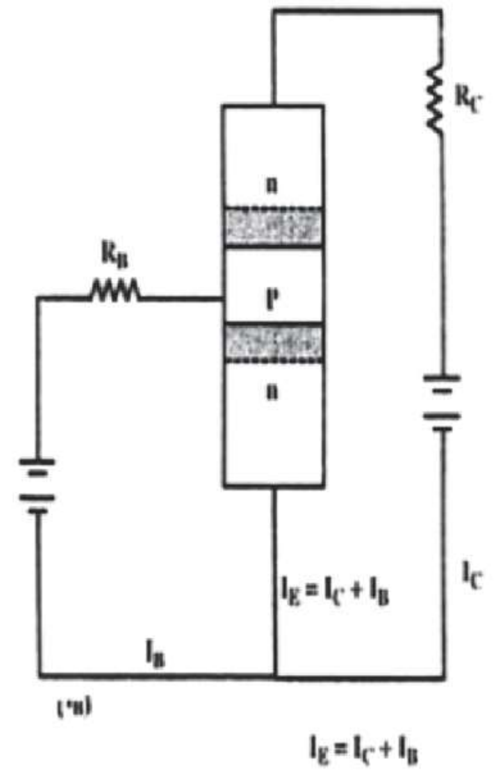


Fig (8-17b)
A transistor amplifier with a common emitter

Transistor as a switch:

Considering the collector circuit, we have

$$\boxed{V_{CC} = V_{CE} + I_C R_C} \quad (8\text{-}9)$$

where V_{CC} is the collector battery, and v_{CE} is the voltage difference between the collecttor and the emitter, I_C is the collector current and R_C is the collector resistance. As I_C increases, V_{CE} decreases, until it reaches a value as low as 0.2V for a high base current. Considering the base as the input ,the collector as the output and the emitter as common (ground), we note that as the input increases, (or positive) the transistor is ON, and the output decreases and vice versa. The circuit behaves as an inverter, for positive voltage in the base (high), current flows in the collector, and the output voltage is very small (low). If the base voltage is small (or negative) or (low). The transistor is OFF and the current in the collector ceases, and the output voltage on the collector increases (high). The transistor as such operates as a switch (Fig 8 -18).

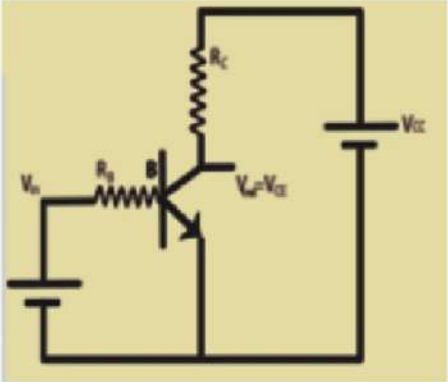


Fig (8 -18a)
Transistor as a switch (ON condition)

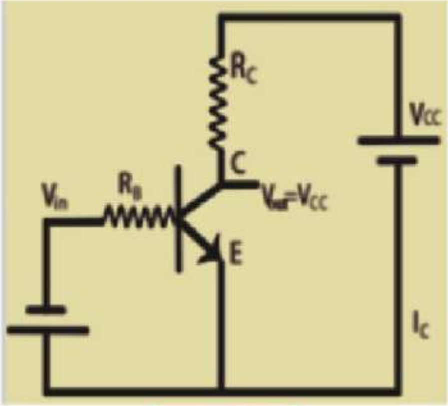


Fig (8 -18b)
Transistor as a switch (OFF condition)

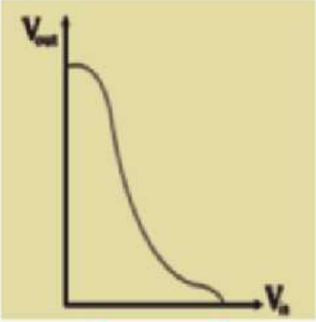


Fig (8 -18c)
Inverter characteristic

Digital Electronics:

All electronic systems deal with natural quantities and convert them to electrical signals. As an example, a microphone converts sound to an electrical signal. A video camera converts an image to electrical signals. In TV, the image (video) and sound (audio) are transformed into electrical signals, then into electromagnetic waves. All this occurs at the transmitter. At the receiver, the em signal is transformed back into electrical (video and audio) signals. The electronics which deals with natural quantities is called analog electronics. A new branch of electronics has developed, namely, digital electronics. In this case, the electrical signal is not transmitted continuously (all values are allowed), but is coded, such that the signal is in terms of one of two possible values representing two states 0 or 1. So, if we want to represent 3, it can be written as 11_2, where subscript 2 denotes the binary system (not eleven).

$$3 = 1x2^0+1x2^1$$

as we may express 17 in decimal system as

$$17 = 7x10^0+1x10^1$$

similarly in the binary system, we use the weights of 2^0, 2^1, 2^2 ... instead of 10^0, 10^1, 10^2, ...Thus, each numeral, symbol and alphabet is coded with a binary code. Analog quantities may be encoded by an analog – digital converter (ADC). At the reciever, digital quantities are decoded into analog quantities using a digital to analog converter (DAC). Why do all this? In nature, there are unwanted spurious signals, called electrical noise. Noise is caused by the random motion of electrons. Electrons are charged particles. As they move randomly, they cause minute randomly varying currents. These currents interfere with and disturb the information - bearing signals. We notice that in weak radio stations, noise appears as a hiss, and in weak TV stations (or with a bad antenna an aerial) noise appears as spots (salt and pepper). Electrical noise marrs the useful signals, and is difficult to get rid of. In case of digital

electronics, the information does not lie in the absolute value of the signal (which might be contaminated by noise), but lies in the code in terms of 0 or 1. It does not matter if the value corresponding to 0 or to 1 has some noise superimposed on it. What matters is the state (0 or 1). This is the main advantage of digital electronics. For this reason, it has permeated our modern life extensively, as in cellular (mobile) telephony, digital satellite TV, and CDs. What has increased the importance of digital electronics is the advent of the computer. Everything that is entered into the computer-whether numbers or letters-must be transformed into a binary code. Even images are divided into small elements, each called a pixel (picture element). These too must be encoded. The computer performs all arithmetic and logic operations using binary (Boolean) algebra. It also stores information in the binary code temporarily in the RAM (Random Access Memory) or permanently in the hard disk, by magnetizing in one direction for 0 and in the opposite direction for 1.

Logic Gates:

Modern applications of electronics, such as computer circuits and modern communication systems depend on digital circuits, called logic gates. These are the circuits that perform logic

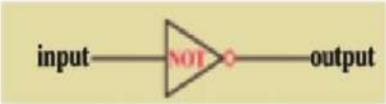


Fig (8-19a)
Not gate symbol

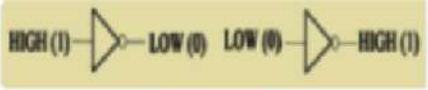


Fig (8 -19b)
States of a NOT gate

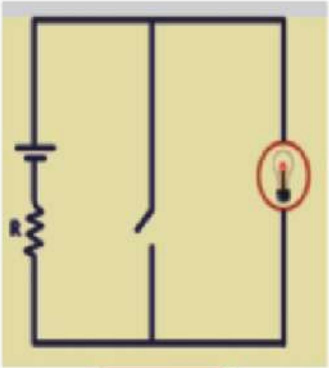


Fig (8 -19a)
An equivalent drawing for a NOT gate. When the switch is closed (ON) the lamp is (OFF) and vice versa

operations, such as inversion (NOT), simultaneity or coincidence (AND) and optionality (OR) as follows :

1) **Inverter (NOT Gate)** has one input and one output, and has the following truth table:

input	output
1	0
0	1

2) **AND Gate:** has two inputs or more and one output and has the following truth table:

input	output
00	0
01	0
10	0
11	1

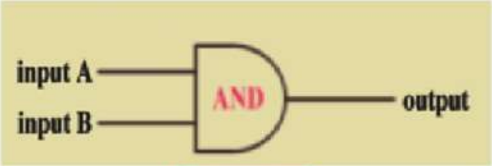


Fig (8-20a)
AND gate symbol

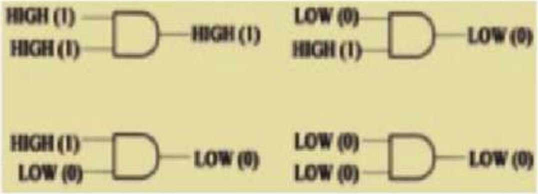


Fig (8-20b)
States of an AND gate

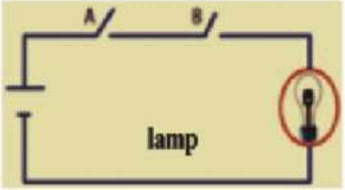


Fig (8-20c)
An equivalent drawing for an AND gate. The lamp does not glow until both switches are closed

Thus, there is no output (1) unless both inputs are (1) each, i.e., two conditions or more are met to satisfy an output (1). It can be represented by two switches in series. They both have to be closed at the same time for current to flow and the lamp to glow.

3) **OR Gate** has two inputs or more and one output (Fig 8-21). One condition (1) may suffice to have an output (1).

input	Output
0 0	0
01	1
10	1
11	1

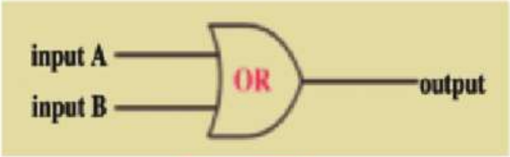


Fig (8-21a)

OR gate symbol

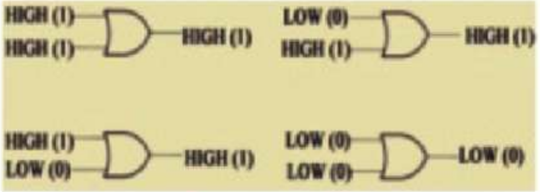


Fig (8-21b)

States of OR gate

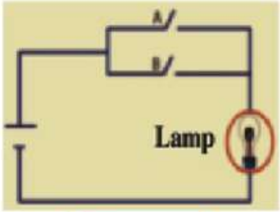


Fig (8-21c)

An equivalent drawing for an OR gate.
One switch need be closed for the lamp to glow

This can be represented by two switches in parallel, one of them only need be closed to pass current.

All operations performed by the computer are based on these gates and others.

These gates can be implemented by transistors.

In this case, the transistor may not be looked upon as an amplifier but as a switch .

Thus, we can use the transistor as an inverter (NOT gate).

A transistor with more than one emitter may be used as an AND gate, so that the transistor will not pass current unless each emitter has positive voltage (1).

Also, we may envision the transistor as an OR gate in the form of a pair of parallel transistors. If (1) exists at either one of the inputs, one of the transistors conducts and (1) appears at the output .

In a Nutshell

- A metallic crystal consists of positive ions and a cloud of free electrons roaming around the crystal in random motion. There is a force of attraction between the ions and the electron cloud. But the resultant of all forces of attraction on a single free electron is zero . If an electron tries to escape from the metal, a net force of attraction due to the atom layer at the surface pulls it in.
- A pure silicon (semiconductor) crystal consists of atoms covalently bonded. At low temperatures, there are no free electrons. If temperature increases, some bonds are broken, electrons become free, leaving behind holes. Both electrons and holes move randomly.
- The number of broken bonds increases with temperature. It may increase also by an external stimulus, such as light, provided that the photon energy is sufficient to break the bond.
- The number of free electrons and holes increases by adding impurities (doping). Thus, the material becomes n-type or p-type.
- The conductivity of a semiconductor depends on the conduction of free electrons and holes. Thus, a semiconductor has two current carriers: electrons and holes, while in a metal there is only one current carrier (the electron). Electron concentration in a metal is constant and does not depend on temperature.
- Semiconductors are environment-sensitive. They can be used as sensors to light, heat, pressure humidity, chemical pollution, radiation etc.
- A diode (pn junction) consists of a p–type region and an n-type region. If the p-side is connected to the positive terminal of the battery and the n-side to the negative terminal

(forward connection or forward bias) current flows. If the battery is reversed no current flows.

This is why a diode is used in rectification.

- A transistor may be pnp or npn, and can be used as an amplifier, since the ratio of the collector current to the base current β_e is large. Therefore, any small change in the base current leads to an amplified change in the collector current.
- A transistor may also be used as a switch. It is used in logic gates, such as an inverter (NOT), AND, OR gates.
- Digital electronics is superceding analog electronics for its ability to overcome electrical noise . Its basic concept is to code information in binary form (0 , 1).

Questions and Drills

I) Drills:

1) If electron or hole concentration in pure silicon is $1x10^{10}cm^{-3}$, phosphorus is added at a concentration of $10^{12}cm^{3}$, calculate the concentrations of electrons and holes in this case. Is this silicon n-type or p-type? ($n=10^{12}cm^{-3}$ $p=10^{8}cm^{-3}$)

(n - type)

2) Calculate the concentration of aluminum to be added so that silicon returns pure .

($N_A^- = 10^{12}cm^{-3}$)

3) A transistor has $\alpha_e = 0.99$. Calculate β_e. Then calculate the collector current if the base current is 100 μA (β_e=99 , $I_C = 99x10^{-4}A$)

4) The electrical signal in the base of a transistor is 200 μA . The collector current is to be 10 mA. Calculate α_e and β_e. ($\alpha_e = 0.98$, $\beta_e = 50$)

5) A diode can be represented by a forward resistance 100Ω ,while it is infinity in the reverse direction. We apply +5 V ,and then reverse it to – 5 V. Calculate the current in both cases. (50 mA, O)

II) Essay questions:

1) Discuss the importance of digital electronics and mention 5 applications.
2) Deduce the truth table for an AND gate followed by an inverter.
3) Deduce the truth table for an OR gate followed by an inverter.

General Revision

1) In electric circuits connected in parallel, thick wires are used at the ends of the battery,but at the ends of each resistor less thick wires are used. Why?

2) What is meant by:

a) the effective value of AC.

b) eddy current.

c) the sensitivity of a galvanometer.

d) the efficiency a transformer.

3) What is the physical concept for the operation of the following devices: galvanometer – transformer – current divider (or shunt)– potential multiplier.

4) Give reason :The step- down transformer increases the current, and the

step - up transformer decreases the current.

5) There are three essential factors that must be considered when designing transformers to decrease the loss of the electric energy. What are these factors and how?

6) Give reason: The eddy current is not generated in the metallic blocks unless a magnetic field of variable intensity exists.

7) Compare between an AC generator and a DC generator.

8) Give reason: To increase the power of a motor ,several coils seperated by small angles are used.

9) The following table shows values of resistance of wire of cross sectional area 0.1 m^2 and different lengths.

Length l m	2	4	6	10	14	16
Resistance R Ω	5	10	15	25	35	40

Plot the relation between the length (l) on the X axis and Resistance (R) on the Y axis. From the plot find:

a) resistance of a part of the wire of length 12 m .

b) the resistivity of the material of the wire.

c) the conductivity of the material of the wire.

10) A wire 30 cm long and 0.3 cm^2 cross sectional area is connected in series with a DC source and an ammeter . The potential difference between the ends of the wire is 0.8 V, when a current of 2A passes through it. Calculate the conductivity of the wire material.

11) A rectangular coil of N turns and surface area A is placed parallel to the lines of a regular magnetic field of flux density B Tesla. If the coil starts rotation from this position with a regular angular velocity ω, until it compelets half a revolution. Clarify with a labeled diagram how the value of the emf changes with the rotational angle during this time, and what is the maximum value of the induced emf generated in this coil.

12) A galvanometer has a resistance 40 Ω and reads up to 20 mA. Calculate the resistance of the shunt required to convert it into an ammeter, reading up to 100 mA. If the coil of the galvanometer is connected to a potential multiplier with resistance 210 Ω.Calculate the maximum potential difference to be read.

13) Compare between each of

a) a step -down transformer and a step- up transformer in terms of function, use, and number of turns of the secondary coil.

b) dynamo and motor in terms of function and use.

14) Why does the transmission of the electric power from a generating station require wires under high voltage?

Choose the correct answer and give account

a) to be able to use the transformers .

b) to insure that the current will flow for a long distance.

c) to minimize the loss in the electric energy .

d) to minimize the resistance of the wires.

15)What is meant by :

a) the coefficient of mutual induction between two coils =2H.

b) the efficiency of a transformer=90%.

c) eddy currents.

d) the effective value of an AC current =2A.

16) A step -down transformer of efficiency 100% is to be used to light a lamp of power 24 W at a potential difference 12 V. If the power source applied to the transformer is 240 V, the number of turns of the secondary coil is 480 turn.

1) calculate the current passing through each of the primary and secondary coils

2) the number of the turns of the primary coil.

17) When an electric current is flowing through a perpendicular wire in a uniform magnetic field, the wire is affected by a force. Which of the following instruments is based on this principle:

(1) electromagnet.

(2) motor.

(3) generator.

(4) transformer.

18) Calculate the emf of a source if the work done to transfer 5C is 100 J.

19) Three resistors 10 Ω , 20 Ω , 30 Ω are connected to a power supply . If the currents are 0.15 A , 0.2 A , 0.05 A, respectively. Calculate the equivalent resistor for this circuit, and illustrate your answer with a labeled diagram.

20) Two resistors 400 Ω and 300 Ω are connected in series to a 130V power supply. Compare between the readings of a voltmeter of resistance 200 Ω when connected across each resistor seperately (neglecting the internal resistance of the power supply).

21) A wire has length 2 m and cross sectional area 0.1 m^2 is connected to a source with emf 10 V. Calculate the resistivity and conductivity of its material if it carries a current of 2A.

22) Two wires are made of copper, the length and mass of the first are 10 m and 0.1 kg, respectively, and those of the other are 40 m and 0.2 kg, respectively . Compare their resistances.

23) A wire of a uniform cross section carries a current of 0.1 A when the potential difference between its terminals is 1.2 V. If a square abcd is made of this wire, calculate the equivalent resistance for the wire when the power source is connected one time to the points a and c, and another time to the points a and d.

24) A power station is connected to a factory 2.5 km away by two wires. The potential difference between the terminals of the wires at the station is 240 V,and that for the other terminals at the factory 220 V.Calculate the resistance of one meter of the wire and its radius, if the resistivity of its material is 1.57×10^{-8} Ω.m and the current flowing through it is 80 A.

25) Find the percentage of the potential drop inside a car battery of emf 12Vand internal resistance 0.5 Ω when connected to a bulb of resistance 2 Ω.

26) Determine the magnetic flux density at a point in air 0.1 m from a long straight wire that carries a current of 10A,where $\mu = 4\pi \times 10^{-7}$ Web/Am.

27) Two parallel straight wires, the first carries a current of 10A, and the second carries a current of 5A.Calculate the total magnetic flux density at a point between the two wires 0.1 m from the first wire and 0.2 m from the second, when the current in the wires is, once in the same direction, and another time in the opposite direction.

28) A current- carrying straight wire is formed as a loop, once from one turn, and another time from four turns. Compare between the flux densities in the center of the loop in the two cases?

29) A long solenoid has 300 turns .What current is required to produce a flux density 1.2×10^{-3} Web/m^2 in the center of the solenoid, if its length is 0.22m? and what is the value of the total magnetic flux in the interior of the solenoid, if its cross sectional area is 25×10^{-4} m^2?

30) A straight wire in a magnetic field makes an angle 30° with its direction. If the length of the wire is 10 cm and the current flowing is 20A, calculate the force on the wire if the magnetic flux density is 2×10^{-3} Web/ m^2.

31) A rectangular coil of length 30 cm and width 20cm consists of 10 turns carrying a current of 3A is placed in a regular magnetic field of flux density 0.1 Tesla.Calculate the torque acting on the coil when the angle between the plane of the coil and the direction of the field is 50°.

32) A circular coil has 100 turns,and carries a current of 10A. It has a cross sectional area of 0.3 m^2 and is placed in a magnetic field of flux density 0.2 Tesla. Calculate the maximum value of the torque acting on the coil, and determine the position of the coil with respect to the field in this case.

33) If the angle between the face of the coil and the magnetic field in a galvanometer is 60°, when a current of 30 mA passes. Calculate the sensitivity of this galvanometer?

34) A galvanometer has resistance 5Ω and full scale deflection 20mA. Calculate the value of the maximum current when a shunt of 0.1 Ω is connected to its coil. Also, calculate the value of the potential multiplier which is to be connected to the galvanometer to make it a voltmeter that reads up to 5V.

35) A shunt of 0.1 Ω decreases the sensitivity of an ammeter by an order of magnitude (10 times). Calculate the shunt resistor which decreases its sensitivity to 1/4 of FSD.

36) Discuss in details the problem which faced classical physics to interpret the curves of radiation versus the wavelength for hot bodies at different temperatures.

37) Explain how Planck was able to clarify the problem of blackbody radiation .

38) What is meant by the photoelectric effect and how did quantum theory explain it?

39) Compton effect is considered a good example for the particle nature of the wave. Discuss.

40) The electron microscope is an applicable example for the wave nature of electrons. Explain the physical concept of this device . Clarify why the electron microscope is superior to the optical microscope?

41) Give reason: Linear spectrum is emitted only in the case of separate atoms or in gaseous state under low pressure.

42) What is the role of the electric field between the cathode and the target in generating X-rays in Coolidge tube.

43) Give reason: The wavelength of the characteristic X- ray spectrum depends on the

type of material of the target and not on the potential difference between the cathode and the target .

44) The active medium must be in population inversion state for laser sources to operate, but that is not essential for ordinary light sources . Why?

45) Resonant cavity is an essential component in laser to complete the amplification and stimulated emission process. Explain the mechanism of both processes .

46) Clarify the role of He and Ne elements in He-Ne laser?

47) He-Ne laser is considered an example for transforming the electrical energy into optical and thermal energy. Explain the mechanism of this transformation .

48) Compare between ordinary photography and holography from the point of view of the way information in the image is recorded.

49) What is meant by a pure semiconductor ? What are its properties as an electrical conducting material ?

50) Discuss ways to increase the conductivity of a semiconductor.

51) Discuss the meaning of the following terms:

- a hole.
- a doping atom.
- internal electric field.
- p-type semiconductor.
- n-type semiconductor.
- current due to the electric field (drift current)
- diffusion current.

52) Discuss the concept of the thermal dynamic equilibrium for a semiconductor crystal.

53) Compare between the properties of a diode in the forward bias connection and in the backward bias connection.

54) Explain with a labeled diagram how a diode performs rectification of an A C current.

55) Explain the physical concept of the transistor as a switch.

56) The least energy required to release electrons out of a metal sueface is 3.975×10^{-19} J. Three monochromatic electromagnetic waves of wavelengths (6000 Å - 5000 Å - 3100 Å) respectively fall onto the metal surface.

Answer for each case:

1- Do electrons emit out of the metal surface?

2- In case of electron emission, ca;culate the kinetic energy and the velocity of the electron.

Given that : (electron mass = 9.1×10^{-31} kg and Planck's constant = 6.625×10^{-34} J.S)

60) Coolidge tube generates X-rays under potenrial difference 4×10^{4} V and current intensity 5 mA. If the efficiency of the tube is 2%, calculate:

1- The shortest wavelength of the produced X-rays. (0.31 Å)

2- The rate of electric energy supplied to the tube (200 W)

3- The rate of X-rays energy produced . (4 W)

Appendixes

Symbols and Units of Some Physical Quantities

serial	quantity	symbol	unit
1	displacement	x,y,z,d	m (meter)
2	area	A	m^2
3	volume	V_{ol}	m^3
4	time	t	s (second)
5	periodic time	T	s
6	velocity / speed	v	$m\ s^{-1}$
7	angle	α,θ,ϕ	deg , rad
8	angular velocity	ω	$rad\ s^{-1}$
9	mass	m,M	kg
10	electron mass	m_e	kg
11	density	ρ	$kg\ m^{-3}$
12	acceleration	a	$m\ s^{-2}$
13	acceleration due to gravity	g	$m\ s^{-2}$
14	linear momentum	P_L	$kg\ m\ s^{-1}$
15	force	F	N , $kg\ ms^{-2}$
16	weight	F_g	N(Newton)
17	torque	τ	Nm
18	work	W	J(Joule)
19	energy	E	J
20	kinetic energy	KE	J

serial	quantity	symbol	unit
21	potential energy	PE	J
22	power	P_w	W , Js^{-1} (watt)
23	impulse	I_{imp}	Ns
24	temperature	$t^{\circ}C$, $t^{\circ}F$, $T^{\circ}K$	Celsius, Fahrenheit, Kelvin
25	quantity of matter	n	mole
26	pressure	P	pascal , Nm^{-2}
27	atmospheric pressure	P_a	pascal , Nm^{-2}
28	quantity of heat	Q_{th}	J
29	specific heat	C_{th}	$J\,kg^{-1}\,{}^{\circ}K^{-1}$
30	heat capacity	q_{th}	JK^{-1}
31	latent heat for evaporation	B_{th}	$J\,kg^{-1}$
32	latent heat for fusion	L_{th}	$J\,kg^{-1}$
33	volume expansion coefficient	α_V	per degree rise
34	pressure expansion coefficient	β_P	per degree rise
35	mass rate of flow	Q_m	kg/s
36	volume rate of flow	Q_V	m^3/s
37	viscosity coefficient	η_{vs}	$Ns\,m^{-2}$
38	efficiency	η	——
39	electric charge	Q,q	C (Coulomb)
40	electron charge	e	C
41	potential difference	V	V (Volt)
42	battery voltage	V_B	V

serial	quantity	symbol	unit
43	electromotive force (emf)	emf	V
44	field intensity	ε	Vm^{-1}
45	electric flux	ϕ_e	Gauss
46	electric current	I	A (Ampere)
47	electrical resistor	R	Ω (Ohm)
48	resistivity	ρ_e	Ω m
49	conductivity	σ	Ω^{-1} m^{-1}
50	transistor gain	α_e , β_e	——
51	magnetic field intensity	H	Am^{-1}
52	magnetic flux density	B	Tesla , Wb m^{-2}
53	magnetic flux	ϕ_m	Wb (Weber)
54	self inductance	L	H (Henry)
55	mutual inductance	M	H
56	permeability	μ	Weber A^{-1} m^{-1}
57	magnetic dipole	$\overrightarrow{m_d}$	Nm $Tesla^{-1}$
58	speed of light	c	ms^{-1}
59	frequency of wave	ν	Hertz (Hz)
60	frequency of electric current	f	Hz
61	wave length	λ	m
62	refractive index	n	——
63	dispersive power	ω_α	——

Appendix 2

Fundamental Physical Constants

Physical Constant	symbol	value
1-Universal gravitation constant	G	6.677×10^{-11} N m^2 kg^{-2}
2-Boltzmann constant	k	1.38×10^{-23} JK^{-1}
3-Avogadro's number	N_A	6.02×10^{26} Molecule.kmol^{-1}
4- Universal gas constant	R	8.31×10^{3} J.kmol^{-1} K^{-1}
5-Coulomb's law constant	K	9×10^{9} Nm^{2}C^{-2}
6-Permeability of free space	μ	$4\pi \times 10^{-7}$ Weber m^{-1}A^{-1}
7-Speed of light in vacuum	c	3×10^{8} m.s^{-1}
8-Elementary charge	e	1.6×10^{-19} C
9- Electron rest mass	m_e	9.1×10^{-31} kg
10-Specific charge of electron	$\frac{e}{m_e}$	1.79×10^{11} C.kg^{-1}
11-Proton rest mass	m_p	1.673×10^{-27} kg
12-Planck's constant	h	6.63×10^{-34} Js
13-Atomic mass unit	u	1.66×10^{-27} kg
14-Rydberg constant	R_H	1.096×10^{7} m^{-1}
15-Neutron rest mass	m_n	1.675×10^{-27} kg
16-Molar volume of ideal gas at S.T.P		22.4×10^{-3} m^3
17-Standard gravity at the Earth's surface	g	9.8066 ms^{-2}
18-Equatorial radius of the Earth	r_e	6.374×10^{6} m
19- Mass of the Earth	M_e	5.976×10^{24} kg
20-Mass of the Moon	M_m	7.35×10^{22} kg
21- Mean radius of the Moon's orbit around the Earth	r_m	3.844×10^{8} m

Physical Constant	symbol	value
22-Mass of the Sun	M_s	$1.989x10^{30}$ kg
23- Mean radius of the Earth's orbit around the Sun	r_{es}	$1.496x10^{11}$ m
24-Period of the Earth's orbit around the Sun	yr	$3.156x10^{7}$ s
25- Diameter of our galaxy	—	$7.5x10^{20}$ m
26- Mass of our galaxy	—	$2.7x10^{41}$ kg
27- Radius of the Sun	—	$7x10^{8}$ m
28- Sun's radiation intensity at the Earth's surface	—	0.134 J cm^{-2} s^{-1}

Appendix 3

Standard Prefixes

power of 10	name
10^{-24}	Yocto
10^{-21}	Zepto
10^{-18}	Atto
10^{-15}	Femto
10^{-12}	Pico
10^{-9}	Nano
10^{-6}	Micro
10^{-3}	Milli
10^{-2}	Centi
10^{-1}	Deci
10^{0}	—
10^{1}	Deka
10^{2}	Hecto
10^{3}	Kilo
10^{6}	Mega
10^{9}	Giga
10^{12}	Tera
10^{15}	Peta
10^{18}	Exa
10^{21}	Zetta
10^{24}	Yotta

Appendix 4

Greek Alphabet

Α	α	alpha	a	"father"
Β	β	beta	b	
Γ	γ	gamma	g	
Δ	δ	delta	d	
Ε	ε	epsilon	e	"end"
Ζ	ζ	zēta	z	
Η	η	ēta	ē	"hey"
Θ	θ	thēta	th	"thick"
Ι	ι	iota	i	"if"
Κ	κ	kappa	k	
Λ	λ	lamda	l	
Μ	μ	mu	m	
Ν	ν	nu	n	
Ξ	ξ	xi	ks	"box"
Ο	ο	omikron	o	"off"
Π	π	pi	p	
Ρ	ρ	rho	r	
Σ	σ, ς	sigma	s	"say"
Τ	τ	tau	t	
Υ	υ	upsilon	u	"put"
Φ	φ	phi	f	
Χ	χ	chi	ch	"Bach"
Ψ	ψ	psi	ps	
Ω	ω	omega	ō	"grow"

Appendix 5

Gallery of Scientists

Ibn Malka (1072 –1152)	A pioneer in medicine and the discoverer of the laws of motion
Ibn Unis (952 –1009)	A pioneer in astronomy and the inventor of the simple pendulum.
Al Baironi (973 – 1048)	A pioneer in geography and astronomy.
Ibn Al-Haytham (965 – 1040)	A pioneer in mathematics, astronomy, medicine and the founder of optics.
Al Kindy (800 – 873)	A pioneer in philosophy, physics , particularly optics.
Edison (Thomas) (1847-1931)	The inventor of the phonograph and the electric lamp, and other inventions "1000".
Arkhimêdês (287 -212 BC)	The discoverer of the ratio of the radius of a circle to its circumference, buoyancy and the reflecting mirror.
Avogadro (Amedeo) (1776 - 1856)	The discoverer of the molcular theory

Ampére (André - Marie) (1775 - 1836)	He performed studies on electricity, telegraph and magnetism.
Oersted (Christian) (1777 - 1851)	The founder of the theory of electromagnetism in 1820
Ohm (George) (1789 - 1854)	The discoverer of Ohm's law
Einstein (Albert) (1879 - 1955)	He was awarded Nobel prize in 1921 for his explanation of the photoelectric effect, the founder of the theory of relativity
Pascal (Blaise) (1623 - 1662)	The discoverer of Pascal's rule.
Al Joazri	A pioneer in fine mechanics and water clocks.
Bragg (William) (1862 - 1942)	The founder of X-ray diffraction.
Bohr (Neils) (1885 - 1962)	He produced a model for the atom.
Boyle (Robert) (1627 - 1691)	The discoverer of Boyle's law.

Torricelli (Evangelista) (1608 - 1647)	The inventor of the barometer
Galileo (Galilei) (1564 - 1642)	The inventor of the telescope and the discoverer of accelration due to gravity.
Galvani (Luigi) (1737 - 1798)	The discoverer of the electric charge in muscles.
Dalton (John) (1766 - 1844)	The discoverer of the law of mixing gases.
Rutherford (Ernest) (1871 - 1937)	The discoverer of radioactivty.
Ruhmkorff (Heinrich) (1803 - 1877)	The discoverer of the induction coil.
Rontgen (Wilhelm) (1845 - 1923)	The discoverer of X-rays.
Schrodinger (Erwin) (1887 - 1961)	The discoverer of Quantum Mechanics.
Al-Khazin	A pioneer in hydrostatics.

Faraday (Michael) (1791 - 1867)	The discoverer of the laws of electromagnetics.
Van Der Waals (Johannes) (1837 - 1923)	The discoverer of Van Der Waals' effect.
Fraunhofer (Joseph Von) (1787 - 1826)	He interpreted the atomic spectra and diffraction
Volta (Alessandro) (1745 - 1827)	The inventor of the battery.
Fermi (Enrico) (1901 - 1954)	He contributed to the atomic bomb.
Kamelingh (Onnes) (1853 - 1926)	The discoverer of liquid helium.
Kepler (Johannes) (1571 - 1630)	The discoverer of the laws of planetary motion.
Copernicus (Nicolas) (1473 - 1543)	He proved that the Earth rotates around the Sun.
Kirchhoff (Gustav) (1824 - 1887)	The discoverer of Kirchhoff's law.

Lenz (Heinrich) (1804 - 1865)	The discoverer of Lenz's rule.
Planck (Max) (1858 - 1947)	The discoverer of the photon and the blackbody radiation.
Maxwell (James)	The discoverer of Maxwell's equations.
Newton (Isaac) (1642 - 1727)	The discoverer of the laws of motion, gravity and colors.
Hertz (Heinrich) (1857 - 1894)	The discoverer of the electromagnetic waves
Huygens (Christian) (1629 - 1695)	He proposed the secondary sources in the from of a wave.
Young (Thomas) (1773 - 1829)	The discoverer of interference.

Appendix 6

Selected Physics Sites on the Internet

http://www.dke-encyc.com

http://imagine.gsfc.nasa.gov

http://csep10.phys.utk.edu

http://www.howstuffworks.com

http://www.colorado.edu/physics/2000/index.pl

http://scienceworld.wolfram.com/physics

http://www.physlink.com

http://www.intuitor.com/moviephysics

http://www.newport.com/spectralanding

http://www.mathpages.com/home/iphysics.htm

http://hyperphysics.phy-astr.gsu.edu/hbase/hframe.html

http://www.smsec.com

مقاس الكتاب	طبع المتن	طبع الغلاف	ورق المتن	ورق الغلاف	عدد الصفحات بالغلاف
١/٨ (٥٧×٨٢)سم	٤ لـــون	٤ لـــون	٨٠ جم أبيض	٢٠٠ جم كوشيه	٢٢٨ صفحة